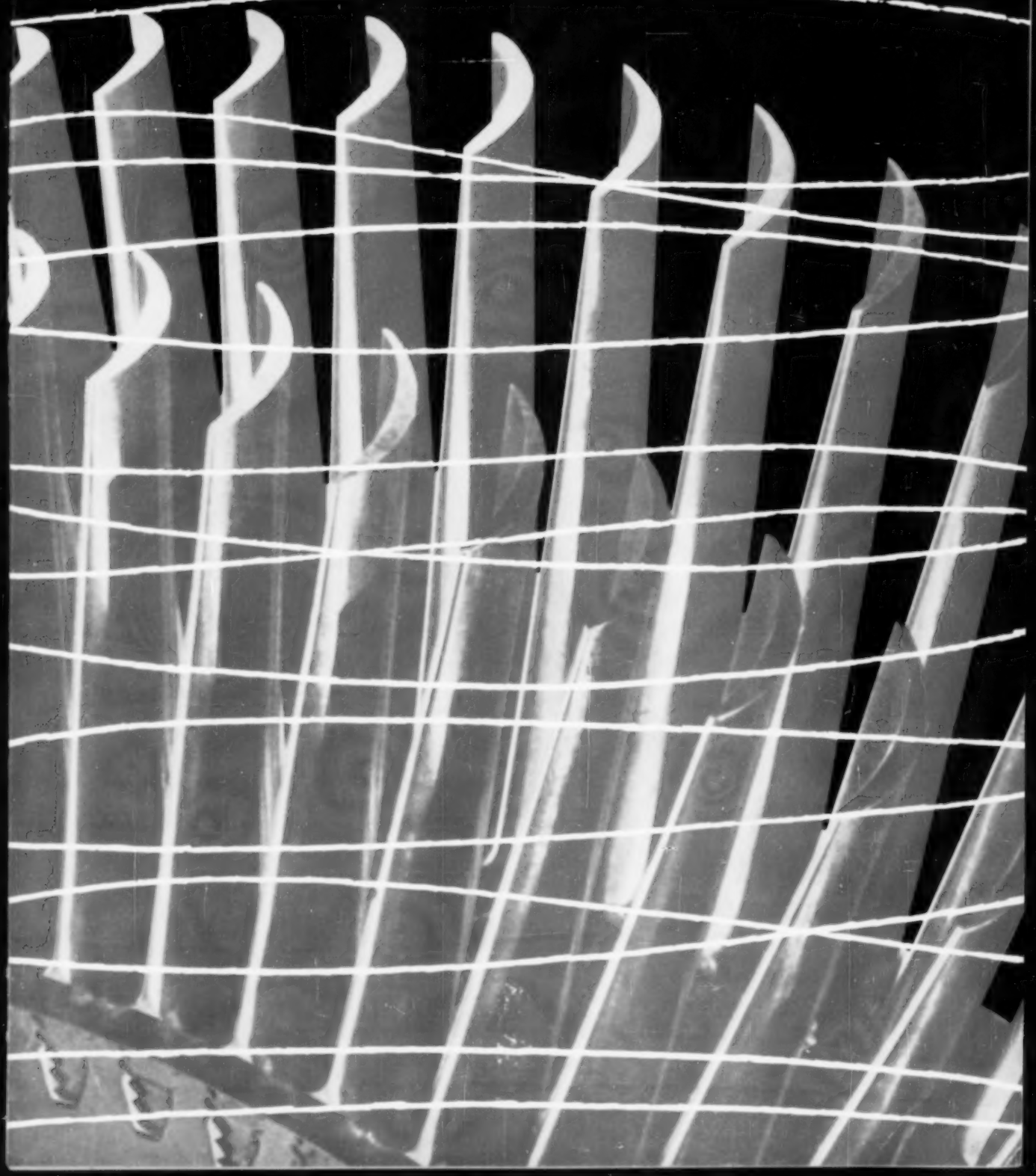
JOURNAL OF

METALS

OCTOBER 1956

IN TWO SECTIONS — SECTION ONE



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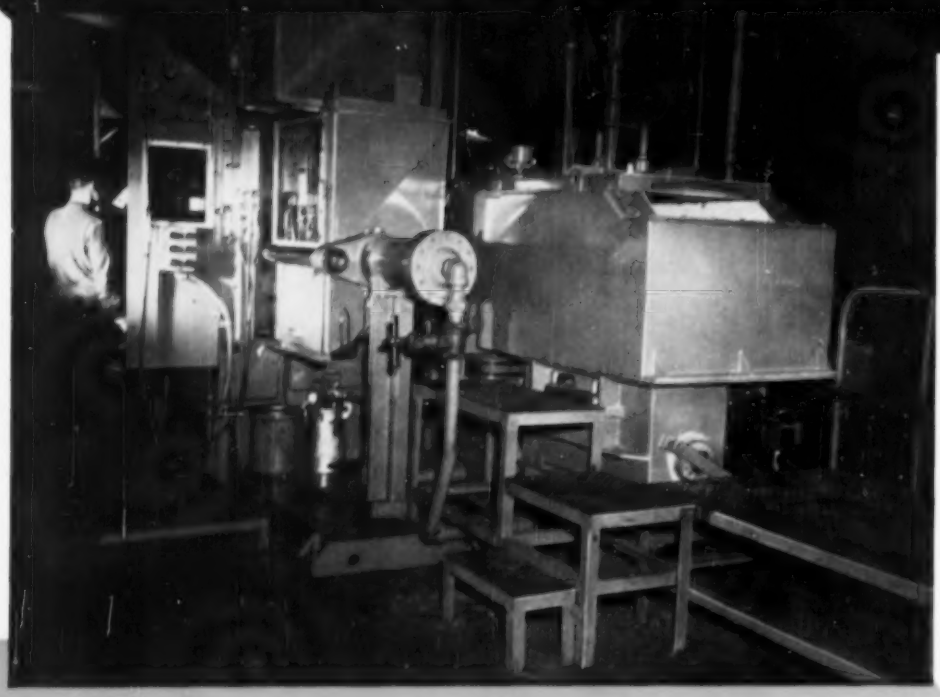

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JOURNAL OF

METALS

VOL. 8, NO. 10

OCTOBER 1956

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This issue of JOURNAL OF METALS is in Two Sections:
1—Magazine 2—Transactions Section

COVER

The changeover to jet and gas turbine engines in aircraft has made alloys with high temperature stress-rupture properties essential. Rotor blades, such as depicted by cover artist Harry Brocke, are subjected to the highest temperatures. The utilization of nickel base alloys for these blades is now the subject of considerable research work, for a review turn to page 1445. The effect of melting and casting atmospheres on such alloys is discussed on page 1450.

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Mill Methods Man or Metallurgical Engineer, B.S. degree in metallurgical or chemical engineering, metallurgy. Will be responsible for the establishment of the material specification, operation sequence, processing standards, and quality checks for the mill operating depart-

(Continued on page 1426)

Additional classified advertising appears on pages 1424, 1426, and 1428.

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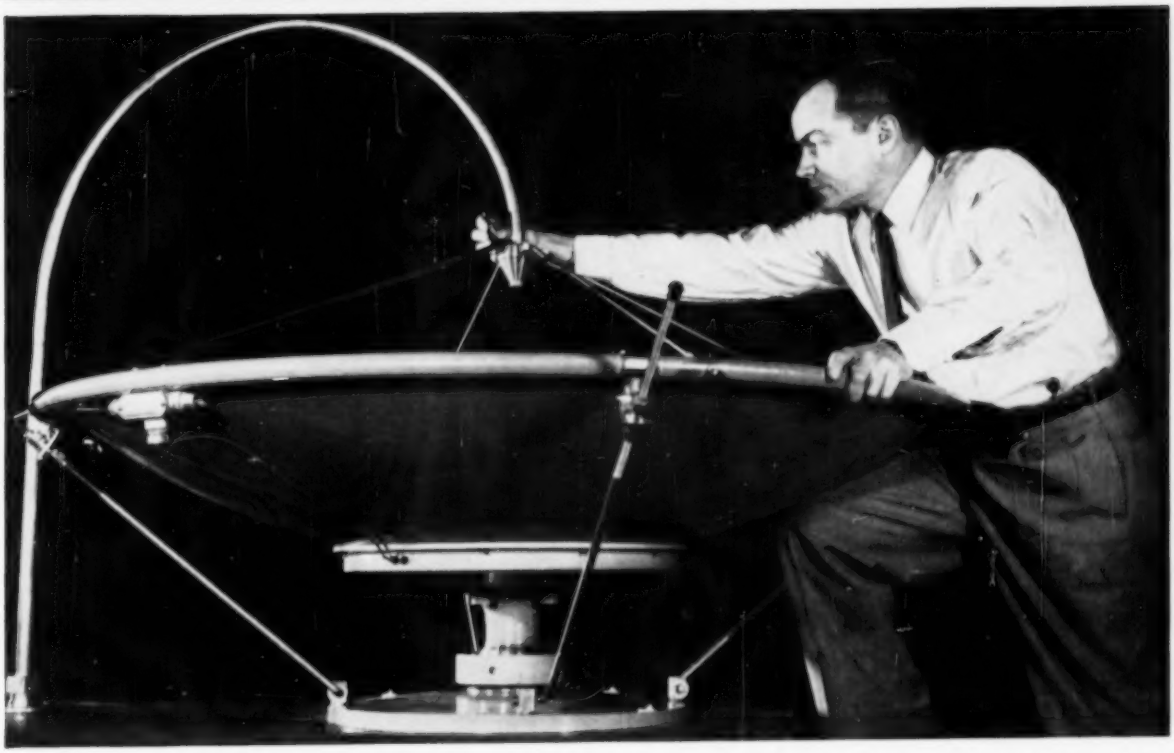

Bell Laboratories' Dr. J. W. Fitzwilliam adjusts a waveguide feed to a parabolic dish reflector. Dr. Fitzwilliam, who has a Ph.D. in physics from Massachusetts Institute of Technology, leads the practical development of Bell's new 11,000-mc. system. Components had to be developed to operate in a frequency band not previously utilized.

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Mr. L. C. Tillotson, who originated the new system, adjusts the klystron-isolator combination which made the system feasible. Mr. Tillotson, an M.S. from the University of Missouri, is in charge of research in microwave applications.

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Personnel Service

(Continued from page 1422)

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(Continued on page 1491)

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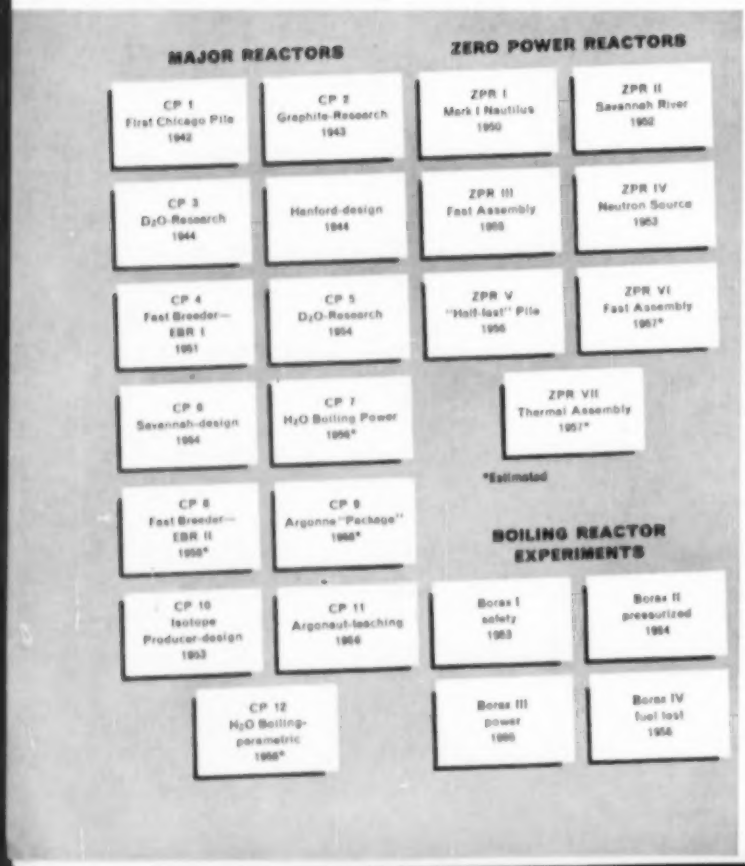
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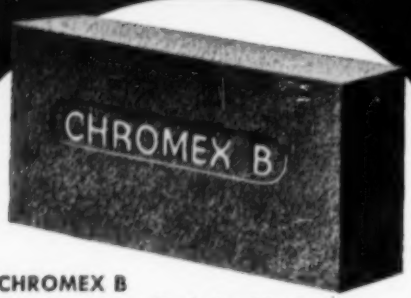

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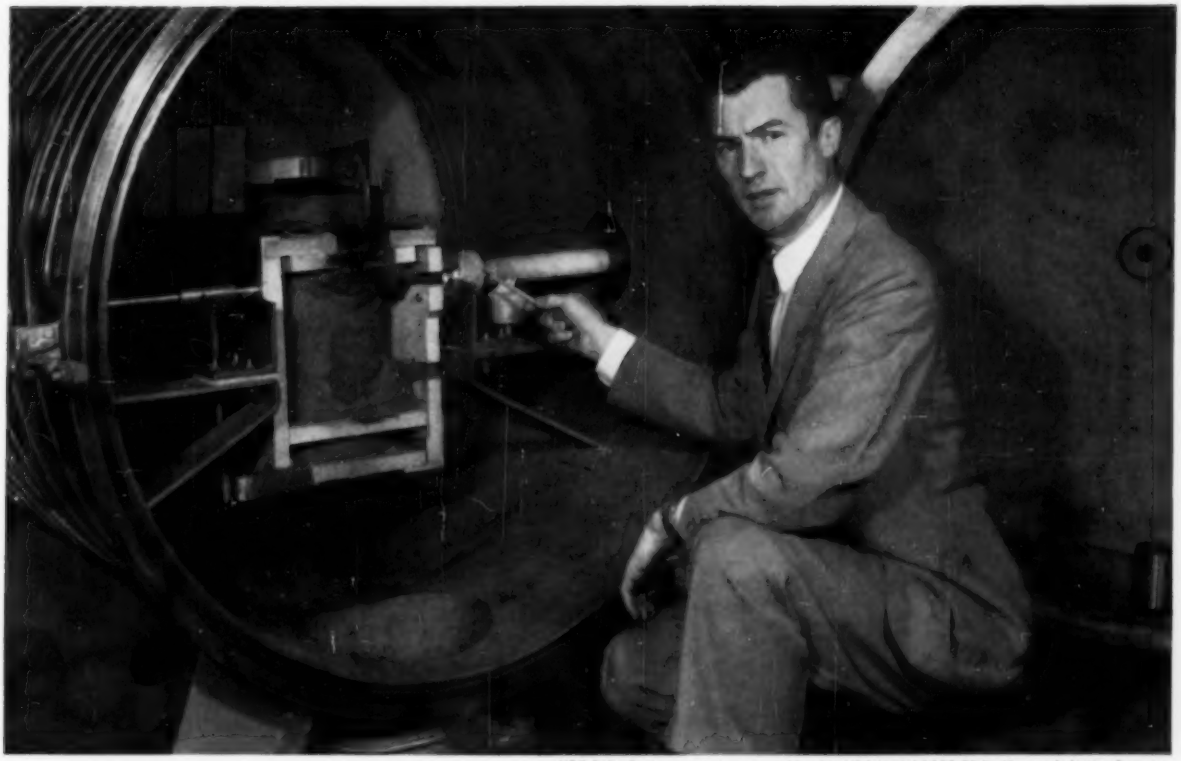

NRC Sales Engineer points to coaxial lead in NRC Model 2555 50-lb. Vacuum Induction Furnace. Co-axial leads are standard equipment in all NRC tilt-pour vacuum induction furnaces.

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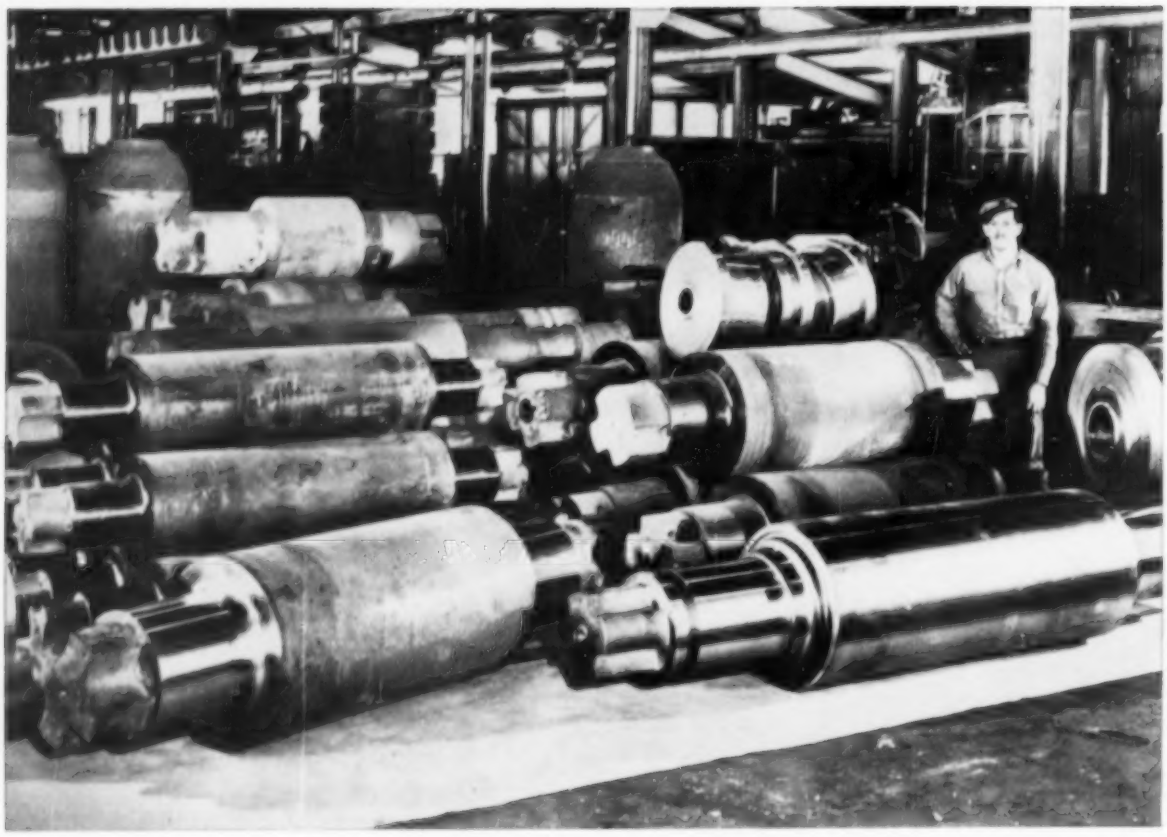


Now . . . Many Types and Sizes of Rolls in ductile cast iron. Strong, tough and rigid, this useful engineering material makes metal-working rolls resist wear and give outstanding performance. Rolls shown were made by Aetna-Standard Engineering Co., Pittsburgh, Pa., a leading producer of ductile cast iron under the trade-name "Magaloy".

Ductile iron rolls give superior results ...reduce breakage, redressing, rolling costs

Many rolling mill operators say that reduced breakage is the chief advantage of ductile iron rolls.

Long service, without redressing, is an equally important benefit, however. In addition, these rolls resist fire cracking. They also produce a fine finish on the metal being worked.

As a result, users get more tonnage of quality rolled output . . . at low cost per ton rolled.

Today, ductile iron rolls are saving money for numerous mills rolling skelp, plate, shapes, structurals, bars, rods and billets. Because specifically desired properties . . . offered separately by conventional roll materials . . . are combined in ductile iron.

And note this particular advantage! Ductile iron rolls possess superior machinability as well.

Try ductile iron rolls. In your own mills. See first-hand how well they perform. Send for a copy of "DUCTILE IRON, The Cast Iron THAT CAN BE BENT!" It gives full details about this economical material, so write for it now.

Ductile Cast Iron gives you the properties that improve metal-working rolls

1. **Wear Resistance**
2. **Heat Resistance**
3. **Toughness**
4. **Rigidity**
5. **High Yield Strength**
6. **Superior machinability**

Despite its high wear resistance, ductile iron is easy to machine. In many fields, it's replacing more costly materials for improvement of products as well as process equipment.

DUCTILE IRON

ductile iron . . . the cast iron that can be twisted and bent

The INTERNATIONAL NICKEL COMPANY, Inc.
67 Wall Street, New York 5, N. Y.

Nickel Supply Picture

For some years defense requirements have continued to aggravate a difficult nickel supply situation. In order to maintain civilian supplies and, at the same time, provide sufficient metal for defense, the U. S. government in 1952 reopened the World War II Nicaro, Cuba, nickel plant. It is now being operated for the government by Nickel Processing Corp., a subsidiary of National Lead Co. In the fiscal year ending June 30th, the plant produced more than 31 million lb, and with an additional investment of $43 million, the capacity will reach 49 million lb in a few years. Nickel oxide from Nicaro is refined at the only commercial nickel refinery in the U. S., the Crum Lynne, Pa., plant of National Lead Co., which commenced operation this June. . . . Incentive for expanding nickel capacity has come from provisions for fast amortization, as well as government contracts to purchase the metal at prevailing market and also premium prices, for companies expanding production. . . . Freeport Sulphur Co. is studying a sulfuric acid leach for laterite ores at Moa Bay, Cuba, which it plans to refine in the U. S. Bethlehem Steel Co. is also experimenting with leaching techniques on ores at Mayari, Cuba. National Lead Co. is attempting to recover nickel and cobalt from a complex sulfide ore at Fredericktown, Mo. And a silicate deposit at Riddle, Ore., is being developed by a M. A. Hanna Co. subsidiary. . . . The U. S. government has also concluded contracts with major Canadian producers, but supplies are not yet adequate and additional premium price contracts are being pushed. By these means the U. S. hopes to increase nickel supplies from some 300 million lb at present to 440 million lb by 1961. . . . U. S. government purchases for the strategic stockpile of nickel, which has reached the halfway mark of its objective, are being diverted this year on a greater scale than heretofore. In 1955 almost 30 million lb were so diverted, while during 1956 more than 74 million lb are scheduled to be diverted to civilian purposes. . . . Thus, both the short and long range offer some slight hope of an improved nickel supply picture.

Low Nickel Stainless on Increase

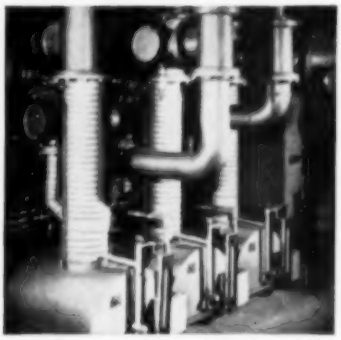
With stainless steels representing up to 25 pct of U. S. nickel consumption, the development of a satisfactory low nickel stainless can be a partial solution to the dilemma of meeting increased demand for austenitic stainless in the face of a continuing nickel shortage. The result of some 25 years' research by Electro Metallurgical Co., Div. of Union Carbide & Carbon Corp., and others is the development of Cr-Ni-Mn stainless steels containing nitrogen, the new AISI types 201 and 202. Type 201, nominally composed of 17 pct Cr, 4 pct Ni, 6 pct Mn, and a maximum of 0.25 pct N, is generally comparable in its physical and chemical properties to type 301, containing 7 pct Ni. Type 202, nominally composed of 18 pct Cr, 5 pct Ni, 8 pct Mn, and a maximum of 0.25 pct N, is comparable to type 302, containing 9 pct Ni. Commercial production of the 200 series started in 1955, and during that year output was 2000 tons. Some estimates place eventual use of these steels at 75 pct of the applications now employing the high nickel types 301 and 302 stainless steels.

Incorporated within vacuum chamber is a rail-mounted ingot mold carriage, which passes through the vacuum lock, moves into position to receive the heat of processed metal and then carries it out on to the mold storage floor. Vertically-hinged door swings fully open, permitting unobstructed access to interior of furnace.

The metals industry is profiting from the use of other STOKES production equipment

Vacuum Metallizers. Stokes offers a complete line of vacuum metallizing equipment to plate metals for improved surface finish . . . also to provide conductive coatings on non-conductive materials.

Powder Metal Presses. Cost savings and the compacting of incompatible alloys have made powder metallurgy an accepted process. Stokes offers the most complete line of presses in the industry.



Vacuum Pumps. For rapid evacuation and holding high vacuums, Stokes offers mechanical pumps, and "Ring-Jet" oil vapor diffusion and booster pumps. New design affords 10 to 100% greater speeds.

Stokes vacuum furnace installed by Allegheny Ludlum for high alloy steel melting

Research studies with new unit will precede production operations on semi-continuous basis

THIS new Stokes high-vacuum furnace was recently installed at the Watervliet, N. Y. plant of Allegheny Ludlum Steel Corporation. It is an important component of the company's new Induction Vacuum Department . . . which, for the immediate future, will devote itself to various aspects of a development program on a wide variety of alloy steels.

Featuring a particularly compact and simplified design . . . the unit permits the direct flow of materials through the chamber, eliminates the need for costly auxiliary equipment, and minimizes the space required for operations. Controls for vacuum pumping, charging, alloying, melting, and casting are centralized and conveniently located.

If you are planning to explore the interesting potential of modern vacuum metallurgy, plan, too, to take advantage of the undisputed leadership in equipment and experience which Stokes can apply to your problem. Prime supplier of vacuum furnaces for production use, Stokes incorporates the features you need for simplified operation and dependable service. With the Stokes vacuum lock, you can make multiple melts and manipulate the melt without breaking the vacuum. High capacity pumping systems, combining new Stokes Ring-Jet Booster Pumps and rugged Microvac roughing pumps, provide fast evacuation and dependable holding of desired vacuum.

A Stokes engineer will be glad to consult on your specific application, help you select the most suitable of the many basic Stokes designs for your work, and engineer modifications to your special requirements. For technical data, write for Stokes Catalog No. 790, "High Vacuum Furnaces."

Reference Data:

Microvac Pumps—Catalog 750
Diffusion and Booster Pumps
Specification and Performance Data
Story of the Ring-Jet Pump
How to Care for Your Vacuum Pump—
Booklet 755
Vacuum Furnaces—Catalog 790
Vacuum Metallizing—Catalog 780
Vacuum Calculator Slide Rule
Powder Metallurgy Today
Powder Metal Presses—Catalog 810

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F. J. STOKES CORPORATION
5524 Tabor Road, Philadelphia 20, Pa.

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The use of Columbium is now free of any restrictions and may be again employed as a valuable alloying material, recognized for improving high temperature properties and increasing corrosion resistance.

In announcing the addition of this product to its line of metallurgical alloying elements, the same reliable MCA technology is offered that has distinguished MCA molybdenum, tungsten, boron and rare earths . . . faithful uniformity in fulfilling specifications . . . deliveries to accurately anticipate customer's requirements.

Further, the sources of supply for the raw material are plentiful, and will continue to increase.

MCA Ferrocolumbium is available in a variety of screen sizes to meet manufacturing requirements. It will pay you to investigate this new supply source, today.

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Sales Representatives: Brumley-Donaldson Co., Los Angeles, San Francisco
Subsidiary: Cleveland Tungsten, Inc., Cleveland
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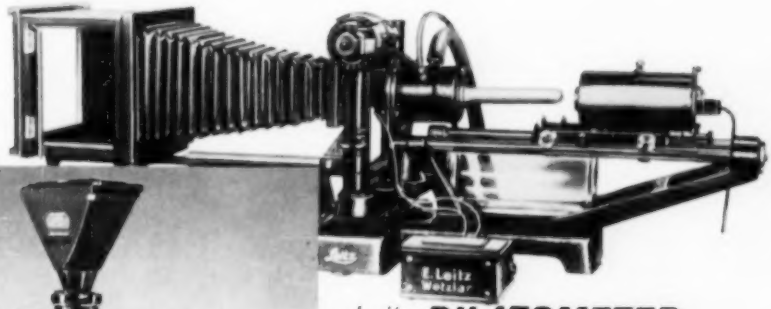
for accurate analytic results
use **Leitz** *precision equipment*



Leitz **DILATOMETER**

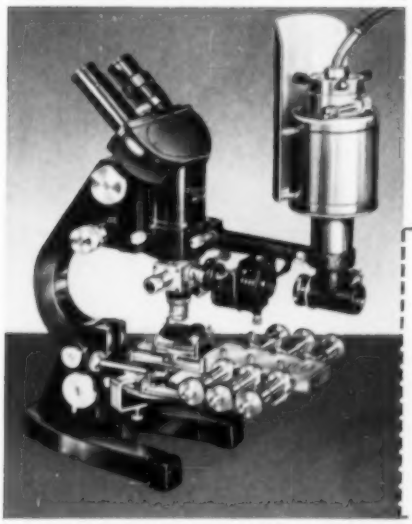
for accurate metal analysis

Researchers consider dilatometric analysis the most sensitive and reliable method for precise determination of the expansion coefficient of metals, alloys, etc. The *DILATOMETER* records volume changes in relation to its own temperature (absolute curve), yielding data from which the expansion coefficient may be determined.

Leitz **METALLUX** *microscope*

for easier, quicker metallography

Metallography is easier with the *METALLUX*—unobstructed upright stage, inclined eyepieces, unique quintuple nosepiece, built-in light and low-position controls for relaxed operation. Accessory equipment available for phase contrast, material testing and photography.



Leitz **KPM** *microscope*

for precise coal petrography

Engineered specifically for coal-petrographic investigation, including examination by polarized or ordinary light, quantitative analysis and microscopic measurement. Fusain analysis readily accomplished by coal slide-comparison eyepiece with revolving disc.

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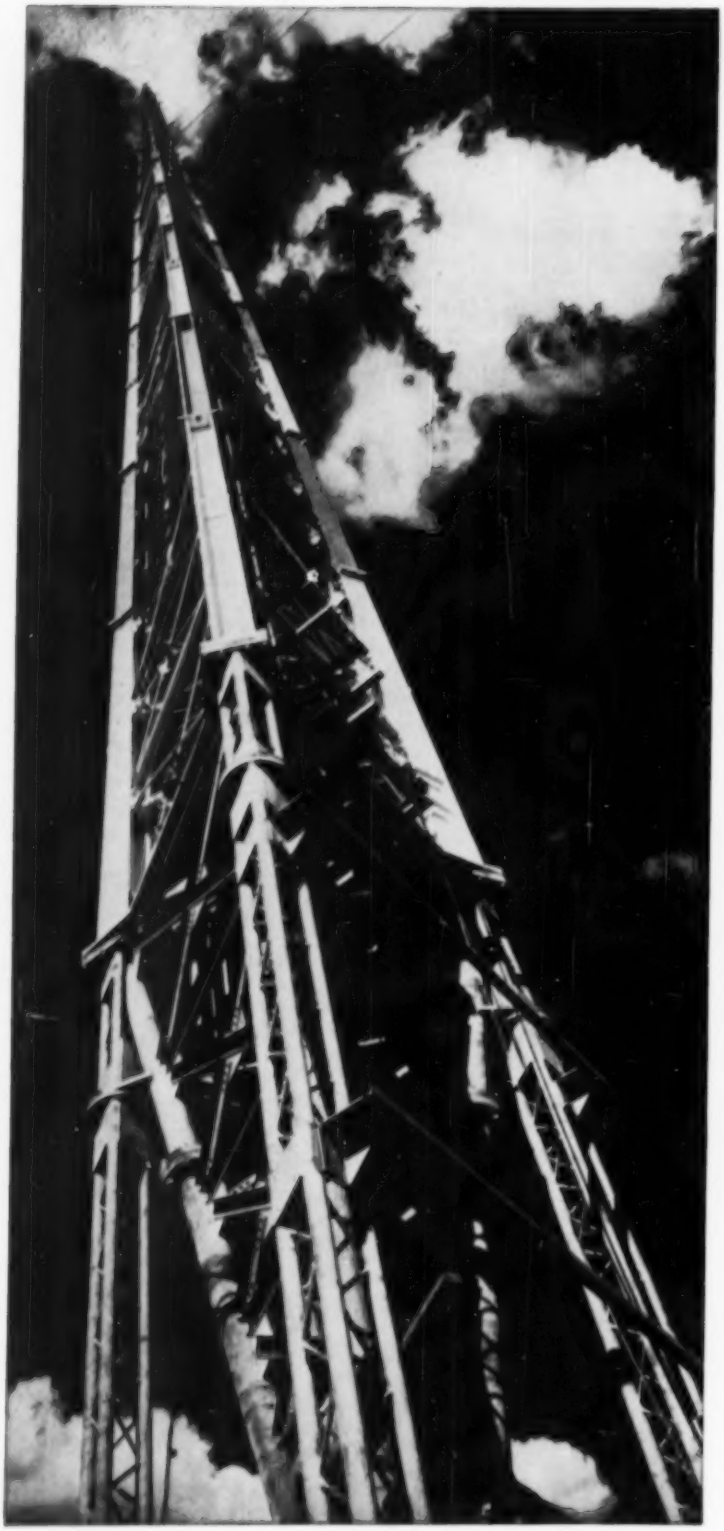

WORLD'S TALLEST MAN-MADE STRUCTURE. 100 ft. higher than the antenna atop the Empire State Building, the 1572 ft. television tower of Station KWTA in Oklahoma City dramatically illustrates the advantages obtainable with USS MAN-TEN Steel in structures where both great strength and light weight are imperative.

USS MAN-TEN Steel supplies the needed strength in the intermediate sections of the tower, 1050 ft. in all, where maximum diameter mild rolled steel rounds were simply not strong enough to carry the load of the tower above.

In the topmost bays, mild steel although strong enough was replaced by lighter, smaller sections of USS MAN-TEN Steel to provide greater or equal strength while at the same time reducing wind resistance so that the structure will be safe in winds up to 150 mph.

RUGGED IS THE WORD. Used in the body liner plates and canopy guard of this 34-ton Rear Dump built by Euclid Division, General Motors Corporation, Cleveland, O., USS TRI-TEN Steel provides 50% greater strength, 60% greater toughness and three times the resistance to atmospheric corrosion of structural carbon steel. And what is of particular importance in equipment like this, that must be able to operate all year around, is TRI-TEN Steel's ability to withstand the shock and impact of heavy, high speed loading even at sub-zero temperatures.

with USS High Strength Steels

In USS High Strength Steels, design engineers have at their command three service-tested steels that will permit them to materially increase the efficiency and economy of machinery, equipment and structures at little or no increase in first cost . . . and frequently, at a saving.

All three of these famous *"steels that do more"*—USS Cor-Ten, USS Man-Ten and USS Tri-Ten—have a 50% higher yield point than ordinary carbon steel. All have better corrosion resistance and offer greater resistance to wear, fatigue and impact. Each, however, has specific superior properties that should be considered in determining its selection.

USS Cor-Ten Steel, for example, is distinguished by its superior resistance to atmospheric corrosion—4 to 6 times that of carbon steel. USS Man-Ten Steel is intended for weight reduction by means of greater strength in moderate forming applications, with enhanced resistance to abrasion and atmospheric corrosion. USS Tri-Ten Steel's outstanding characteristics are excellent weldability and resistance to shock at low temperatures.

Used singly or in combination, these steels can advantageously replace carbon steel to increase the strength and durability of vital parts *without* increasing their weight. Or when the use of thinner sections is feasible, they can (1) reduce equipment weight without reducing its strength, or (2) increase the size and capacity of equipment without increasing total weight or the power required to move it.

• • •

You will find our 174-page *"Design Manual for High Strength Steels"* extremely useful in applying the benefits of these steels to your product. Send for free copy—simply write on your company letterhead to United States Steel Corporation, Room 5510, 525 William Penn Place, Pittsburgh 30, Pa.

HARD-WORKING FARM EQUIPMENT lasts longer, is more dependable when built with USS Cor-Ten Steel. Here used in the main axle and tractor hitch frame of the famous John Deere No. 12-A Combine, USS Cor-Ten Steel gives these vital parts maximum strength, maximum toughness with no increase in weight and at the same time ensures high fatigue resistance—50% greater than that of plain carbon steel. Racking and twisting strains that could easily cause a breakdown are safely absorbed by Cor-Ten Steel's high endurance limit—and the equipment stays on the job.

STRENGTH AND TOUGHNESS are prime requisites in boom boats like this. Used by logging firms to buck logs in the sawmill pond to the log haul-up, these busy little vessels receive very rough treatment, are frequently squashed between the huge logs they handle. To ensure all the strength possible in the hull, sides and bottom are plated with Cor-Ten Steel, welded both inside and out. Cor-Ten Steel's greater abrasion resistance and its high resistance to corrosion also play an important part in prolonging life. (Built by the Ilwaco Boat Works, Ilwaco, Wash.)

1933 UNITED STATES STEEL USS HIGH STRENGTH STEELS 1956
23 YEARS OF PERFORMANCE

UNITED STATES STEEL CORPORATION, PITTSBURGH • AMERICAN STEEL & WIRE DIVISION, CLEVELAND
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USS HIGH STRENGTH STEELS

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INSTRUMENTATION FOR RESEARCH, MATERIALS CONTROL AND PRODUCTION

- X-ray Diffraction Equipment
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- Industrial Image Intensifiers with Closed Circuit Television

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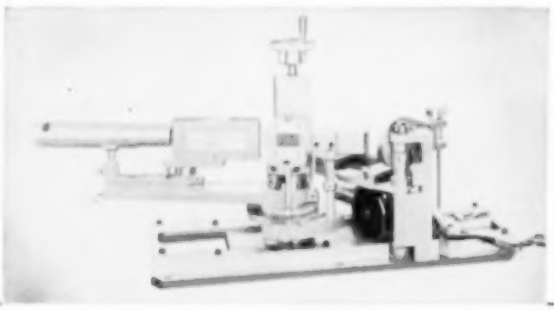
NORELCO SPECTOGRAPHIC

Now includes light as

X-ray Spectrography provides non-destructive analytical data from the characteristic X-ray fluorescence related to the atomic properties of elements. This method produces dependable and reproducible results in a fraction of the time required by chemical and other means. The advantages of speed and accuracy of X-ray fluorescence over other means, are now even more important. New developments in routine detection techniques and instrumentation have extended the usefulness of the X-ray Spectrograph to include elements of low atomic number—down through magnesium, (Atomic #12) for both qualitative and quantitative analyses.

NEW INSTRUMENTATION

For routine production analyses, several special specimen holders have been designed to facilitate placement of varied-shaped specimens in the X-ray path—thus speeding specimen preparation and analysis.



ANALYSIS FOR ANY INDUSTRY...
well as **heavy** metal fields

Accurate determinations can be made from trace amounts to 100% of a given element—in a matter of minutes without necessity of film or plate standardization or processing techniques. The equipment is readily operated by laboratory personnel.

Norelco analytical instruments are available for many industries, many diverse and complex fields. Perhaps your production difficulties can be greatly simplified. You are invited to visit our Application Laboratories or write today—our field engineers are available for consultation without obligation.

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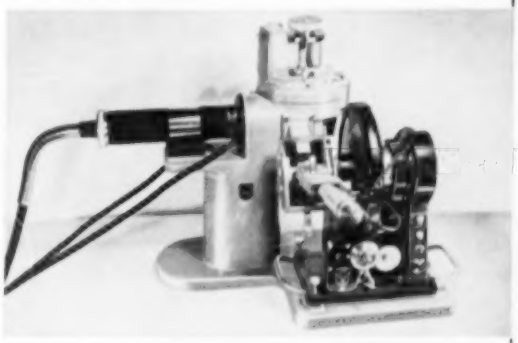
BULK-SPECIMEN HOUSING

This spectrographic unit is designed for fluorescence analysis of large slugs or billets, with a minimum of surface preparation. The unit is ideal for production analysis, since sample size is not critical and preparation time is minimized. It will accommodate samples up to two inches in depth and ten inches square.

THREE-SPECIMEN HOUSING

Three openings facilitate repetitive loading and provide many practical advantages. The unit is equipped with a rotating spinner to average out surface effects. Powder analysis is simplified, since mylar window presentation surface is on the underside of the sample holder. Gravity loading simplifies liquids analysis—specimen surface is at constant height above X-ray beam. Resistance-heated holders are available for maintaining mean temperatures or liquefying greases, etc.



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SPECIAL SPECIMEN HOUSINGS

Numerous special spectrographic units have been devised for repetitive presentation of finished or semi-fabricated parts in the X-ray path. For example, a special bearing analyzer is designed to render quantitative analysis of platings on cylindrical crankshaft bearings to an accuracy of one percent—with an average checking time of ninety seconds.

STANDARD SPECIMEN HOLDER

The standard spectrographic unit is favored for research as well as industrial uses and can be applied to all investigations requiring diversified specimen preparation techniques.

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NORTH AMERICAN PHILIPS COMPANY, INC.

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Proposed Bylaws of The

In November 1955, Mr. J. H. Scaff, the 1955 Chairman of the Metals Branch, appointed a committee of representatives from the Extractive Metallurgy, Institute of Metals, and Iron and Steel Divisions to draw up a set of new Bylaws for the Metals Branch. The committee was instructed to develop a set of Bylaws that would conform to the dictates of the AIME Long-Range Planning under the chairmanship of Mr. Andrew Fletcher.

The Metals Branch task force met in New York on Jan. 5, 1956, and conceived the basic framework of the new Bylaws. A draft of the Bylaws was drawn up by Messrs. J. S. Smart, Jr., and R. W. Shearman and mailed to all officers and executive committee members of the three divisions of the Metals Branch prior to the AIME Annual Meeting. The new Bylaws were very thoroughly discussed at the regular Annual Meeting and at a special meeting of the Metals Branch Council in New York in February.

With the very constructive suggestions of the officers of three Divisions, many worthwhile changes and additions have been made to the Bylaws. I think that a description of the latest draft of the Bylaws given on these two pages would be in order.

At the June 1956 Meeting of the Board of Directors two important decisions were reached:

a) A special committee headed by Grover Holt was appointed to rewrite the Bylaws of the AIME.

b) The Metals, Mining, and Petroleum Branches were instructed to make the necessary changes to the latest draft of their new Society Bylaws to conform to the new AIME Bylaws prepared by Mr. Holt's Committee, and to submit the corrected Society Bylaws to the AIME Board of Directors for approval.

It is hoped that the final draft of the Bylaws of the Metallurgical Society of AIME will be finished in time to be submitted to the AIME Board of Directors in November 1956.

A. W. THORNTON, *Chairman,*
Metals Branch Council

Name

This unit of the American Institute of Mining, Metallurgical, and Petroleum Engineers Inc. shall be known as the Metallurgical Society of AIME.

Object

The object of the Society is to promote the advancement of metallurgical knowledge and the advancement of the metallurgical profession as a whole by:

a) Providing a medium for communication and cooperation among those interested in all phases of theoretical and applied metallurgy, including those advancing, practicing, learning, or otherwise primarily concerned with the science, engineering, economy, or technology of the metals industry (both producers and consumers). The major metallurgical fields encompass particularly the understanding and knowledge of metal behavior, the manufacturing practice for extracting, refining, and fabricating metals, and the development and application of metals and their alloys.

b) Providing an organization to represent the metallurgists and metallurgical engineers on matters pertaining to education.

c) Dissemination of metallurgical knowledge by the holding of professional meetings, and by the preparation, presentation, discussion, and publication of technical papers.

d) Encouraging and advancing education in the broad field of metallurgical science and engineering.

e) Promoting high standards in the profession of metallurgical engineering.

Members

Any member of AIME in good standing may become a member of the Society by indicating his choice in writing to AIME headquarters.

Funds

Rules are given for the handling of funds by the Society and submission of an annual budget to AIME.

Meetings

The Society shall meet at the same time and place as

Metallurgical Society of Aime

the Annual Meeting of AIME and at such other times as may be determined by the Executive Council.

Officers

The officers of the Society shall consist of President, Vice-President, Past-President, and Secretary-Treasurer.

The Executive Council shall consist of the following persons:

a) President
b) Vice-President
c) Past-President
d) Secretary-Treasurer
e) Three representatives from each Division

The Society shall be represented on the Board of Directors of AIME by six Directors as follows:

a) Past-President of the Society
b) President of the Society
c) Vice-President of the Society
d) Three Directors, elected for a three-year term, but initially one each for three, two, and one years.

Divisions

The Society shall consist of Divisions as established by the Executive Council, and initially comprise Extractive Metallurgy, Institute of Metals, and Iron and Steel.

Committees

Standing Committees shall be:

a) Finance Committee
b) Programs Committee
c) Publications Committee
d) Membership Committee
e) Education Committee
f) Nominating Committee
g) Committee on the Metallurgical Profession

Nominations and Elections

A Nominating Committee shall consist of three members from each Division, selected by each of the Division Nominating Committees. The President of the Society shall select one member to serve as Chairman.

The Nominating Committee shall designate nominees for Vice-President (the President-Elect) of the Society, representatives on the AIME Board of Directors, and the President of the Institute every third year.

Amendments

Rules are given for amending the Bylaws.

Implementation of Long-Range Planning for Institute Development

Some appropriate sections from the report of the Study Committee for Implementation of the Long-Range Plan (as they apply to the proposed Bylaws of the Societies of AIME) are given below. For the full progress report of the Study Committee see pages 1054 and 1055, JOURNAL OF METALS, August 1956. The text of the Long-Range Plan was given on pages 802 and 803, JOURNAL OF METALS, June 1956.

2. **Branches**

a) The Mining Branch and the Petroleum Branch Councils are favorably inclined to the names *Society of Mining Engineers* and *Society of Petroleum Engineers*, respectively. The Metals Branch prefers the name *Metallurgical Society of the AIME*. It is recommended that section 2a **be implemented**, with these changes, upon approval of the Society bylaws.

b) It has been resolved by this committee that the activities of *MIED* and *MED* are of overall Institute interest and that they are certainly not peculiar to any one of the Societies. This suggests that these two groups function in their all-Institute capacity and be responsible to the AIME Board and not to the governing bodies of the Societies. Several of the Technical Divisions in the Branches already have education and extension committees. Wherever the need is felt for these committees, they should continue to function, but universally no pressure need be applied to other Divisions to form such committees until a need is recognized. It is believed that these existing divisional committees should be coordinated with the existing *MIED* and *MED* and that each of the two Institute boards Divisions be represented to the AIME Board by a contact director to be appointed by the AIME President, and to be appointed from the 21-man "working Board." It is further recommended that the two groups be designated as Divisions rather than as Councils, to avoid confusion with the Executive Council of the Societies. It is suggested that the title of Board of Directors be reserved for the AIME Board and that the governing body of the Societies be designated as the *Executive Council*.

c) This section **will be implemented** upon approval of the new Society bylaws; however, section 2c should be expanded to include the residence. Alterations in the bylaws of the Societies must be approved by the AIME Board of Directors.

3. **Directors**

a) This section **will be implemented** upon approval of the new Society bylaws and will require a revision of the AIME bylaws.

b) This section **will be implemented** upon approval of the new Society bylaws and will require a revision of the AIME bylaws.

c) The committee **prefers** the wording suggested by the Inter-Branch Council recommendations on Long Range Planning as published in the agenda for the meeting of the Board of Directors, AIME, June 20, 1956.

Transportation, but not food or housing expenses, when requested by the Society which the director represents and approved by the Executive Committee of AIME shall be paid by the AIME.

However, the **implementation** of this section **will depend** upon a revision of the AIME bylaws.

d) The recommendation stated here is **a reiteration of the present policy** and is recognized to be beyond the scope of the Societies. The proposed bylaws of the three Societies recognize the sovereignty of the AIME.

4. **President**

(Continued on page 1490)

for steel or non-ferrous metals

FIVE SPECIAL TITANIUM ALLOYS

Whatever your low-carbon titanium requirement, there's an ELECTROMET titanium alloy to suit your melting practice. ELECTROMET produces three standard grades of low-carbon ferrotitanium, each grade containing a maximum of 0.10 per cent carbon. Of special interest to producers of high-quality forgings are the low aluminum and silicon contents of this alloy, which make ELECTROMET ferrotitanium specially suited for the production of forgings having good mechanical properties.

ANALYSIS OF "ELECTROMET" LOW-CARBON FERROTITANIUM

Element	30% Titanium Grade	50% Titanium Grade	70% Titanium Grade
Titanium	27-32%	50-55%	68-72%
Aluminum	0.15% max.	0.15% max.	0.15% max.
Silicon	0.10% max.	0.10% max.	0.10% max.
Carbon	0.10% max.	0.10% max.	0.10% max.
Size	2 in. x Down	2 in. x Down	2 in. x Down

OTHER TITANIUM ALLOYS

Silicon-Titanium		Manganese-Nickel-Titanium	
Titanium	40-50%	Titanium	46.5-48.5%
Silicon	45-50%	Manganese	6-8%
Iron	3.00% max.	Nickel	29-31%
		Aluminum	12.5-14.5%
Sizes: 2 in. x Down, 1 in. x Down, 20 Mesh x Down		Size: 2 in. x Down	

ELECTROMET also produces a silicon-titanium and a manganese-nickel-titanium alloy. Silicon-titanium is available for adding titanium to either non-ferrous alloys or steels where the simultaneous addition of silicon is desired. Manganese-nickel-titanium is available for adding titanium to nickel-base high-temperature alloys.

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Past, Present, and Future of High Temperature Nickel Base Alloys

Based on an Article by
F. L. VerSnyder

NICKEL base alloys for elevated temperature service can properly be dated from the invention of Nichrome, in 1906.[1] At that time A. L. Marsh patented the 80 pct Ni-20 pct Cr alloy, as well as other nickel-chromium alloys, for use as electrical resistance elements. The characteristics which most commended Nichrome for resistor service were toughness, ductility and good oxidation resistance at temperatures of the order of 1100°C. Solid solutions of nickel, chromium, and iron were also investigated in the early part of the century.[2] Inconel (80 pct Ni, 15 pct Cr, 5 pct Fe), and others containing more iron, were developed because of their lower comparative cost.[3] A parallel development was the Hastelloy series of alloys[4, 5] which, though primarily developed for their resistance to corrosion by hydrochloric acid, were also being considered for their high temperature characteristics. The Hastelloys are basically iron-nickel-molybdenum alloys.

The period 1936 to 1938 saw Pillings and Merica[6] in this country, Chevenard[7] in France, and Rosenhain and others[8] in England publish results indicating the beneficial effect of titanium and aluminum on room and high temperature properties of nickel-chromium alloys. Early patents concerned themselves primarily with room temperature properties and applications, although some work did include high temperature creep tests.

World War II marked the beginning of active development of super-alloys—alloys possessing outstanding high temperature strength characteristics, whose intended use required unusual static and dynamic strength at temperatures from 1200°F to 1800°F.[9] British effort resulted in the Nimonic Alloys, which were studied intensively. A wide range of alloys was studied in this country. Early bucket alloys for jet engines were of the Hastelloy type,[9] and later, these were replaced by cobalt base S-816 alloy.[10] Development of nickel base alloys was simultaneously carried on in this country, but it was not until after World War II that they came into prominence. Today, among the most promising alloys for elevated temperature service are titanium-aluminum precipitation-hardened nickel base alloys.

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Chemical Composition

Table I presents chemical compositions of some important nickel base alloys. Chromium is present in appreciable amounts in most alloys, usually to promote scaling resistance. In excess of about 20 pct, chromium does not add substantially to the scaling resistance and frequently has adverse effects on the forgeability; consequently, chromium content of most alloys is in the range 15-20 pct where maximum scaling resistance is developed. Iron is usually present as a residual or tramp element and does not ordinarily exceed 7 pct in this type of alloy. Cobalt and molybdenum may or may not be present, depending on the nature of the alloy. Carbon in significant amounts—0.1-0.3 pct—is found in those alloys dependent on carbides for grain size inhibition or as precipitation hardeners. In other alloys it was found that carbon did not contribute to the strength or other desirable characteristics of the alloy. Titanium and aluminum are the principal precipitation promoting additions. Aluminum originally found its way into nickel base alloys more or less by accident. At first, it was either a natural impurity of the master-alloy additions or was added as a deoxidation agent during melting. Today, most nickel base alloys used for elevated temperature service contain both titanium and aluminum, with the trend

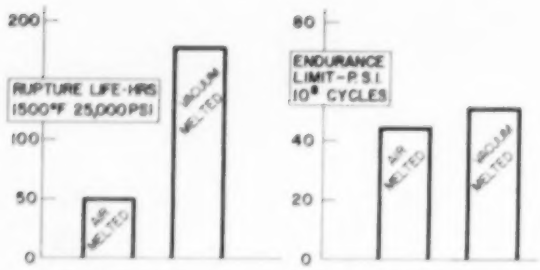


Fig. 1—Comparison of stress-rupture and fatigue properties of nickel base alloys, air and vacuum melted.

towards increasing these additions to the highest practical limit. A few alloys also have molybdenum present as a strengthener.

Melting, Casting, and Processing

Melting and casting simple nickel base alloys is generally similar to steel.[11] But the more complex alloys, particularly those containing titanium and aluminum, have caused several modifications in technique. Satisfactory results for complex compositions have been obtained with air melting, both in induction and in arc melting facilities. Arc melting in air is extremely important in making sufficient quantities of these alloys available. A problem specific to air melted nickel base alloys containing titanium was the presence of undesirable inclusions, identified as titanium nitride and carbonitride.[12] These inclusions, particularly when present as *chains* or *stringers*, caused serious forging difficulties, and when present in *clusters*, affected the machinability. The difficulties were solved by using selected titanium master-alloy additions, observing special care in melting and pouring temperatures, and protecting the melt from the atmosphere during melting and casting. These practices lead to increased titanium recovery and cleaner heats.

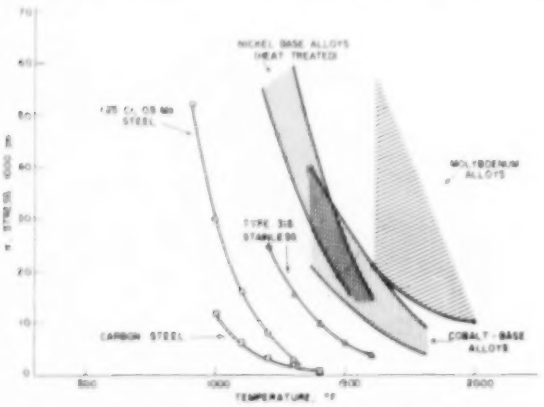


Fig. 2—Stress-rupture properties of nickel base alloys, as compared to other materials. 1000 hour rupture value.

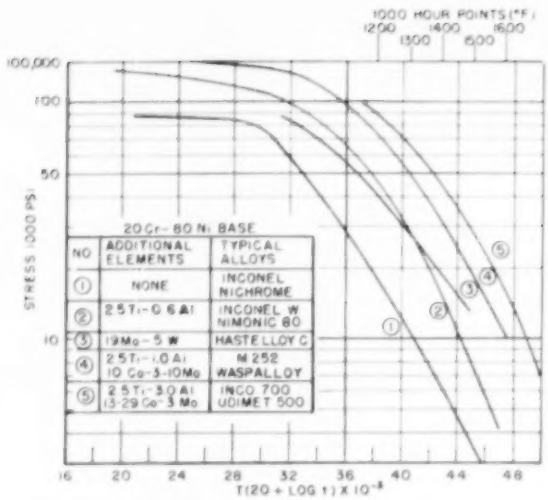


Fig. 3—Stress-rupture plot for various nickel base alloys. Additional elements substitute for nickel in the composition. Method of plotting is the Larson-Miller parameter.

It is expected that air melting will be used for producing nickel base alloys containing 2 to 3 pct titanium, but vacuum melting appears to be the only practical method for producing alloys containing more titanium. Considerable effort is currently being spent on development of vacuum melting as a production technique.[13,14] Vacuum melting of nickel base alloys, even though they may be produced by air melting, has certain advantages; for example, rupture life of current bucket materials shows a measurable advantage for vacuum melted material, Fig. 1, and there is also a slight advantage in the fatigue strength. However, evaluation of vacuum

Table I. Typical Chemical Compositions of Nickel Base Alloys, wt pct

Alloy	C	Ni	Cr	Co	Mo	W	Cb	Ti	Al	Fe	Other
Nichrome	0.25	80	20	—	—	—	—	—	—	1.0	—
Hastelloy A	0.10	56	—	—	22	—	—	—	—	22	—
Hastelloy B	0.10	62	—	—	32	—	—	—	—	6	4 Va
Hastelloy C	0.10	53	17	—	19	5	—	—	—	6	—
Inconel	0.04	80	15	—	—	—	—	—	—	5.0	—
Inconel W	0.04	78	15	—	—	—	—	2.5	0.6	7.0	—
Inconel X	0.03	73	15	—	—	—	0.6	2.3	0.9	6.5	—
Inco 550	0.03	73	15	—	—	—	0.6	2.5	1.1	6.5	—
Nimonic 75	0.12	76	20	—	—	—	—	0.4	0.06	2.4	—
Nimonic 80	0.05	76	20	—	—	—	—	2.3	1.0	0.5	—
Nimonic 80A	0.05	76	20	—	—	—	—	2.3	1.0	0.5	—
Nimonic 90	0.08	58	20	16	—	—	—	2.3	1.4	0.5	—
Nimonic 95	0.08	58	20	16	—	—	—	2.5	1.6	0.5	—
Rex 400	0.09	76	19.2	—	—	—	—	2.1	0.6	2.0	—
K42B	0.06	42	15	23	—	—	—	2.6	0.6	13	—
INCO 700	0.10	46	15	29	3.0	—	—	2.0	3.0	1.0	—
INCO 702	0.02	80	15	—	—	—	—	0.5	3.0	0.35	—
INCO 703	0.08	80	10	—	2.6	—	—	2.4	2.95	0.40	—
INCO 709	0.10	80	9	—	3.0	—	—	2.75	3.75	0.40	—
INCO 710	0.10	77	0.25	—	3.0	—	—	2.7	3.65	0.40	—
Multi-Alloy	0.25	46.5	20.5	3.3	2.7	3.5	2.9	1.2	—	19	—
Waspalloy	0.08	58	19	13	2.5	—	—	2.5	1.0	3.5	—
Refractalloy 26	0.03	37	18	20	3.0	—	—	3	0.25	19	—
Udimet 500	0.10	55.6	19.4	13.7	4.15	—	—	2.95	2.87	0.6	—
Hastelloy R235	0.10	64	16	1.5	5.5	—	—	3.0	1.5	8	6 Si
M 252	0.12	54	19	10	10	—	—	2.5	1.0	3.5	—

melting has been on comparatively small heats—of the order of 600 lbs—so, it is not quite fair to compare these results to 10-ton air melted heats. Much of the data presented, which indicate superiority of vacuum melting, may well be due to size effect.

Many alloys discussed here are used in the wrought condition. Ingots of the alloy are usually rolled or forged to bar stock, then precision forged to the desired shape. Generally, alloys which respond to heat treatment are then solution annealed and aged prior to finishing operations.

Naturally, the critical nature of the alloys and

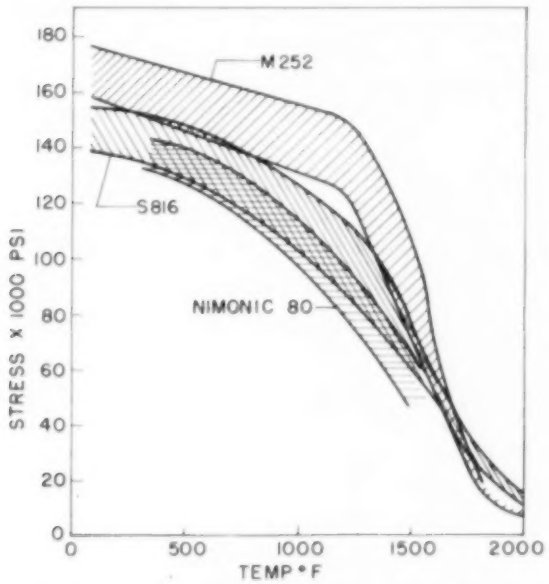


Fig. 4—Comparison of tensile properties of nickel base and cobalt base alloy, courtesy AISE.

their economic utilization indicate the desirability for a high recovery of bar stock from the original ingot. While with some alloys, such as M252, forging or rolling techniques give a recovery of useable bar stock from an ingot or billet of 50 to 60 pct, extrusion can increase recovery up to 90 pct.[15] Since extrusion facilities are currently available in many plants, this technique may be adopted to give high yields at high production rates. High temperature alloys are generally extruded using the French process of glass fiber insulation and lubrication.[16] This process facilitates extrusion as well as substantially lengthening die and container life.

Mechanical Properties

One of the most important characteristics of a high temperature structural material is its stress-rupture strength. The relationship of this property of nickel base super alloys to other structural materials is given in Fig. 2. Nickel base alloys are generally considered for application in the range of 1200-1500°F, while cobalt base alloys are favored more for temperatures somewhat beyond 1500°F, and molybdenum alloys are strong contenders for use at much higher temperatures. With increased development of the nickel base alloys, it is expected that the practical service temperature will be raised. For example, stress-rupture strength for a series of nickel base alloys with increasing alloy complexity is presented in Fig. 3. It can be seen that, as strengtheners, particularly titanium and aluminum, are added to the 80 pct Ni-20 pct Cr base, rupture strength for any time-temperature combination is decidedly increased. There is some overlap in the properties of the nickel base alloys; however, it may be seen that the alloys (e.g. the International Nickel Co. 700 alloys) containing higher titanium and aluminum content definitely have higher rupture strength.

One of the most stringent applications of high temperature super-alloys is in the aircraft gas turbine bucket. An indication of the potential of nickel base alloys for elevated temperature service can be seen by examining properties of three alloys, two of which are nickel base.[17] The two nickel alloys chosen were Nimonic 80, of the titanium-aluminum precipitation hardening variety, and M252, which has a number of alloying elements and whose reactions are complicated by the presence of carbides. The other alloy, the cobalt-base S816, has been standard as a bucket material for the last six years. Comparative properties are given in Figs. 4, 5, and 6. Tensile strength of M252 is somewhat higher at lower temperatures, but all three alloys converge in value at 1500°F, Fig. 4. While stress-rupture strength of M252 is superior at lower test temperatures—1200-1500°F—the S816 alloy is more resistant to flow at temperatures above 1500°F, Fig. 5. In fatigue, both the cobalt-base S816 and the nickel base M252 alloys have strength superior to Nimonic 80, M252 having a slightly higher fatigue strength than S816 at higher temperatures, as shown in Fig. 6.

From the standpoint of high temperature properties, it looks promising for nickel base alloys. However, it remains to be seen if large quantities of the more complex alloys can be produced as dependable engineering materials.

Alloying and Structure

Properties of nickel base alloys are dependent on their structure; so, this should explain the mechani-

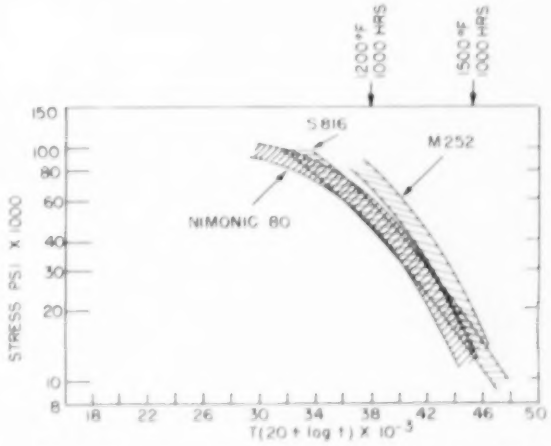


Fig. 5—Comparison of stress-rupture properties of nickel base and a cobalt base alloy, courtesy AISE.

cal behavior of the alloys, e.g. the Nimonic type, which is precipitation hardened primarily by nickel intermetallic compounds, and the M252, whose reactions are more complicated. The Nimonic alloys are low in carbon and have a simple microstructure. The M252 alloy has more carbon—0.15-0.20 wt

pct—and has cobalt and molybdenum as alloying elements.

The solid solution hardening effect of some alloying elements is of interest here. The strengthening effect of the solute atoms is a function of at least three variables; a) lattice strain related to atomic size differences, b) change in electronic configuration of the solution resulting from the solute addition, and c) possible short-range ordering of the solute in the solvent. The strengthening effect of a solute for a fixed lattice strain may be seen by plotting strengthening increment (e.g. $\Delta\sigma$ y.s.) versus change in lattice parameter[10] (Δa_o). Such a relationship for dilute solutions of titanium, aluminum, molybdenum and vanadium in an 80 wt pct nickel, 20 wt pct

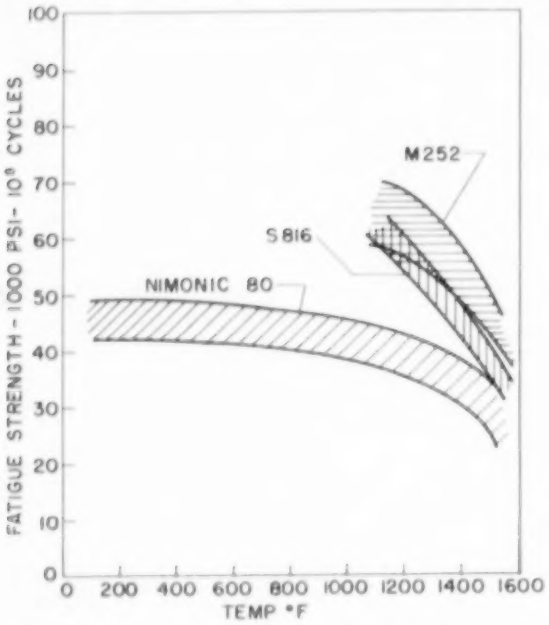


Fig. 6—Comparison of high temperature fatigue strengths of nickel base and a cobalt base alloy, courtesy AISE.

chromium base is given in Fig. 7. Both copper and aluminum alloys exhibit similar linear relationship of yield strength vs. alloy content for dilute solutions. It may been seen that increasing the amount of solute elements increases yield strength. Titanium is the most potent solid solution hardener. On the basis of differences in atomic size and valency, aluminum might be expected to contribute more to solid solution hardening, but this does not appear to be the case. In general, the total effect of adding small amounts of a number of solutes may be obtained by totaling the effect of each solute. However, there is evidence that additions of small amounts of a variety of solutes is sometimes better than a corresponding total amount of a single solute. Effectiveness of solutes generally become less at higher solute percentages.

Precipitation of a second phase or phases from a saturated solid solution usually causes a marked increase in the strength of nickel base alloys. The phases present in high temperature super-alloys as particle strengtheners are usually intermetallic compounds or carbides. In nickel base alloys both types are observed; the Nimonic alloys are representative of the former, and M252 is perhaps dependent on both types of particles as strengtheners.

If titanium, aluminum, or both are added to an 80 wt pct nickel-20 wt pct chromium alloy, there are two compounds which might be expected, depending on the titanium to aluminum ratio: Ni_3Ti or Ni_3Al. A consideration of the phase diagrams[10] (Ni-Ti-Al; Ni-Cr-Al; Ni-Cr-Ti) indicates that Ni_3Ti (η phase) takes practically no nickel, chromium, or aluminum into solution. Ni_3Al (γ' phase) dissolves a considerable amount of these elements, e.g. up to three out of every five aluminum atoms could be replaced by titanium.

To obtain maximum particle hardening effect, a precipitate which achieves coherency with the matrix is desirable. In this case both structures are close packed (HCP and FCC respectively), as is the matrix (FCC) of nickel base alloys. It would appear that the closest match between precipitant and matrix would be achieved in the case of the Ni_3Al, where the precipitant is primarily an ordering of the solid solution. In view of solubility and coherency factors, it would appear that the Ni_3Al phase would be the particle hardener most likely to raise the useful service temperature of nickel-base alloys; so, the titanium to aluminum ratio should be increased toward the end of the homogeneity range for the Ni_3Al phase, and the sum of titanium and aluminum contents should be increased to the limits permitted by fabrication or processing.

The difference between the two alloy types can be illustrated by considering the microstructures. Nimonic 80, when aged for 10 hr at 1700°F, would appear to be a single phase solid solution. On the other hand, the M252 alloy, when similarly aged, Fig. 8, contains a considerable amount of secondary phases—large spheroidal M_6C carbides and grain boundary precipitation. Upon aging at 1700°F for 50 hr, a considerable amount of very fine precipitation takes place in the matrix, as shown in Fig. 8c. Considering the fact that the carbide forming elements, chromium and molybdenum, as well as the precipitation promoting elements, titanium and aluminum, are present in the M252 type alloys, complicated behavior would be expected. At the lower molybdenum contents, of the order of 2 to 3 wt pct and possibly up to 4 wt pct Mo, one of the principal precipitating phases is the carbide $M_{23}C_6$. X-ray diffraction, electron diffraction, and microscopic studies have shown that this phase is instrumental in effecting the precipitation hardening observed by hardness and other mechanical property tests. As Mo content of this type alloy increases, the $M_{23}C_6$ carbide is replaced by M_6C carbide. It has not been shown that this carbide causes precipitation hardening. As molybdenum content is further increased, up to 11 wt pct, one finds the presence of sigma phase. To date, studies of the kinetics of precipitation in M252

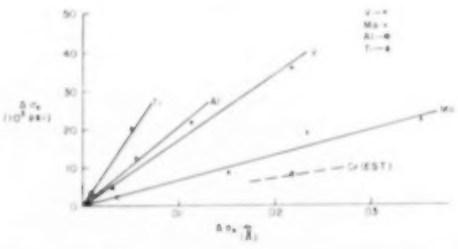
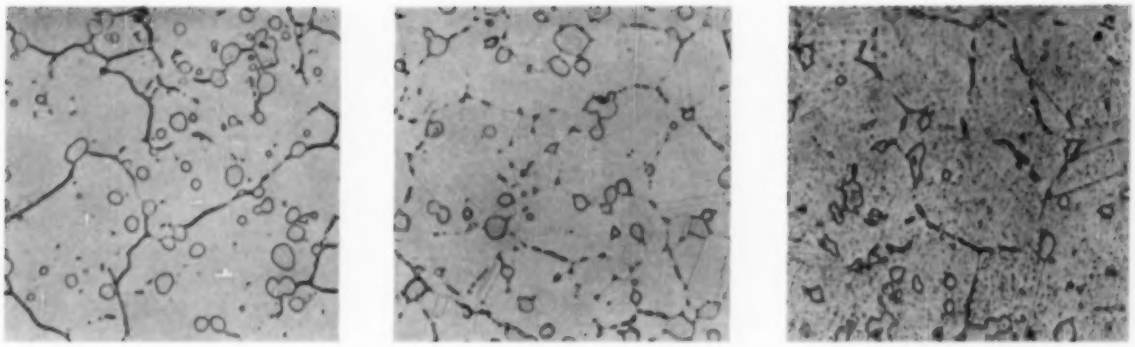


Fig. 7—Relation between increment in yield strength and change in lattice parameter for an 80 wt pct Ni-20 wt pct Co base, courtesy R. Guard.



a b c

Fig. 8—Microstructures of aged alloy M252. All specimens given a 1950°F, 4 hr, air cool, solution treatment, and then aged at 1700°F, for a) 10 min, b) 10 hr, and c) 50 hr. All specimens air-cooled. Etchant: 92 pct HCl, 5 pct H_2SO_4, 3 pct HNO_3. 500X.

type alloys have failed to reveal the important structural features promoting the elevated temperature strength and stability at high molybdenum contents.

A determined search for precipitation of titanium intermetallic compounds has been made in the M252 type alloys. Although various X-ray and electron diffraction techniques have been applied, no evidence has as yet been shown for the precipitation of

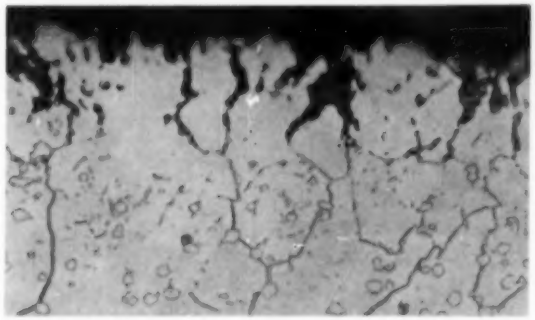


Fig. 9—Microstructure illustrating intergranular oxide penetration present in the surface of a nickel base alloy after forging. Etchant: 92 pct HCl, 5 pct H_2SO_4, 3 pct HNO_3. 500X.

phases such as Ni_3Ti or Ni_3Al.[7] This is by no means conclusive evidence that these compounds are not present and active as particle hardeners; it only indicates the elusiveness of these phases to present techniques.

In general, studies of structural changes occurring in nickel base alloys—age hardened with titanium and aluminum—have been directed toward finding an alloy serviceable for gas turbine rotor blades, rather than collection of fundamental data. Collection of this data has followed after the alloys were in production and had seen varying degrees of service. It is hoped that in the future this research will be carried out before rather than after the fact.

Special Problems—Manufacture

There are two special problems in the manufacture of turbine buckets which must generally be considered when dealing with nickel base alloys. The first is the comparatively low recrystallization temperature of nickel base alloys, and the second is the problem of intergranular oxidation of the alloys during various stages of metallurgical processing, Fig. 9. Subsequent service conditions may then bring about: 1) recrystallization of a cold worked layer, obtained during finishing of the blade, thereby lowering high temperature resistance to deformation at the surface; and 2) growth of cracks initiated by the presence of intergranular oxidation. Fortunately, both problems can be solved by electromachining in the final stages of processing. This will remove the cold worked layer and any intergranular penetration which has resulted from the manufacturing process.

Summary

Nickel base super-alloys appear to have an extremely bright future if they can be made into reliable engineering materials capable of being produced in production quantities. The trend towards higher titanium and aluminum is consistent with our knowledge that increasing amounts of solute elements improves creep resistance of a solvent, and that precipitation of a second phase, if it is adjusted properly, can increase the resistance to rupture. In applications where static and dynamic stresses are comparatively high, increased study of both present complicated alloys and utilization of fundamental work on simple systems should lead to a better understanding. When this has been accomplished, higher useful service temperatures will be attained.

References

[1] P. D. Merica: Nickel, Modern Uses of Non-Ferrous Metals, AIME, 1935, p. 229.
[2] N. B. Pilling and P. D. Merica: U. S. Patent No. 2,048,167, July 21, 1936.
[3] L. Aitchison and W. R. Barclay: *Engineering Non-Ferrous Metals and Alloys*, Henry Frowde and Hodder and Stoughton, London, 1923.
[4] L. W. Parr: *Development of An Acid Resistant Alloy*, Trans. American Institute of Metals, 1915, vol. 8, p. 2a.
[5] A. W. Clement: *Turbine Blading Analysis* U. S. Patents Nos. 1,375,082 and 1,375,083, April 19, 1921.
[6] P. Chevenard: *Revue du Nickel*, 1935, vol. 6, pp. 4-12; *Chaleur et Industrie*, 1936, vol. 17, pp. 125-137.
[7] W. Rosenhain, C. H. M. Jenkins et al: *Journal of the Iron and Steel Institute*, 1930, No. I, pp. 225-236, and 237-304; 1931, No. I, pp. 313-341; 1937, No. II, pp. 187-220.
[8] C. L. Clarke: *High Temperature Alloys*, Pitman Publishing Corp., 1953.
[9] F. S. Badger and W. O. Sweeney: *Symposium on Materials for Gas Turbines*, ASTM, 1946.
[10] Gunther Mohling: U. S. Patent No. 2,397,034, Mar. 19, 1946.
[11] C. Bieber: ASM Handbook, 1948.
[12] H. J. Beattie and F. L. Ver Snyder: *Trans.* ASM, 1953, vol. 45, p. 397.
[13] J. H. Moore: *Metals Progress*, October 1953, vol. 64, p. 103.
[14] Electrochemical Society: *Vacuum Metallurgy*, papers presented at Vacuum Metallurgy Symposium of the Electrothermic and Metallurgy Division at Boston, Mass., Oct. 6-7, 1954.
[15] W. E. Jones, Jr.: private communication.
[16] R. L. Coughlin et al: *Metal Working Tomorrow*, Harvard Graduate School of Business Administration, April 24, 1954, p. 62. Also New Twist on Hot Extrusion, *Iron Age*, Jan. 21, 1954.
[17] F. L. Ver Snyder: Problems in Developing Alloy Steels for Aircraft Gas Turbines, *Iron and Steel Engineer*, May 1954, p. 115.
[18] R. W. Guard: *G. E. Research Lab. Tech Report No. RL 1174*, Sept. 1954.
[19] A. Taylor and R. W. Floyd: *Journal of the Institute of Metals*, 1953, vol. 81, pp. 25, 451.
[20] H. J. Beattie and F. L. Ver Snyder: to be published.

Effect of Melting and Casting Atmospheres on Cast Nickel Alloys

In the past, improvement of heat-resistant cast alloys was dependent upon new compositions. By contrast, this work is directed toward determining the effect of melting and casting atmospheres on the properties of existing nickel base alloys, particularly their rupture strength and elongation at elevated temperatures. Increased strength was most pronounced in high-boron alloys of the Guy type, while improvement in ductility was apparent in all cases.

Based on an Article by
C. M. Hammond and R. A. Flinn

ALLOYS for better service at elevated temperatures have become essential as a result of the utilization of gas-turbine engines in aircraft. The materials used are critical, since the rotor blades in these engines are subjected to high temperatures and stresses. Initially, cobalt base alloy blades were used, but the cost of this metal has led to development of nickel base alloys.[1,2,3] Research has been concentrated on variations in chemical analyses correlated with changes in stress-rupture properties at 1500°F, and most of the alloys so developed contain titanium or aluminum or both. Since these elements are known to give casting difficulties through severe metal oxidation and gas solution during melting, it was questioned whether or not the published properties represented the true potential of these materials. It appeared important to have more knowledge of the effects of melting and casting atmospheres and other processing variables upon the room temperature and stress-rupture properties of promising nickel base alloys.

A survey of the literature indicated that at present the Guy,[1] Inco 700,[2] and GMR 235[3] alloy types are the most promising; their properties and compositions are shown in Table I. All three materials contain considerable percentages of titanium and aluminum, making melting and casting atmospheres significant in determining ultimate properties.

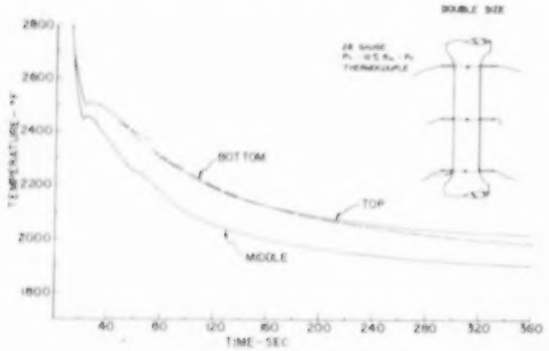


Fig. 1—Test bar cooling curves.

C. M. HAMMOND and R. A. FLINN are International Nickel Research Fellow and Professor of Metallurgy, respectively, University of Michigan, Ann Arbor, Mich.

Preliminary Experiments

Before entering the principal phases of the investigation, it was necessary to establish specimen design, gating design, and pouring practices which would produce properties similar to present published results.

Specimen Design: It was feared that the present standard test bar—0.250 diam, 1-in. gage length—would contain excessive center-line shrinkage in the gage length. Fortunately, the degree of directional solidification in the standard bar was sufficient to produce radiographically sound bars in all cases. Occasional center-line microshrinkage, too fine to affect the radiographs, was encountered.

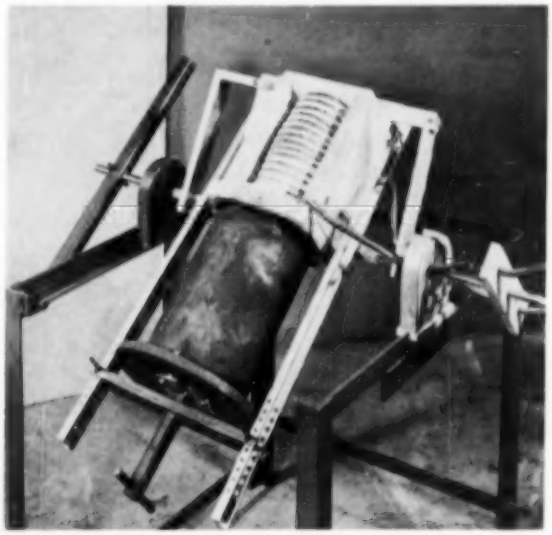


Fig. 2—Air and argon-protected melting equipment, showing mold clamping and rollover mechanism.

Fig. 3—Vacuum plus argon melting furnace, showing interior of vacuum shell with the induction furnace, mold, charging buckets, and dipper.

Table I. Properties and Nominal Compositions of Three Promising Cast Nickel-Base Alloys

Alloy Type	100-Hr Rupture Strength, Psi	Pct Elongation at 100 Hr	Compositions Pct								
			C	Cr	Mo	Al	Fe	Ti	B	Co	Cb
Guy[1]	48-50,000	3-5	0.10	13	6.0	6.0	4.5	—	0.50	—	2.0
*Inco 700[2]	41-43,000	10	0.10	15	3.0	3.0	.5	2.0	—	28	—
GMR 235[3]	38-40,000	6-10	0.15	15.5	5.25	3.0	10.0	2.0	0.075	—	—

* Properties from wrought specimens, solution treated 2160°F for 2 hr and air-cooled, aged at 1600°F for 4 hr and air-cooled.

Table II. Pouring Temperatures of the Three Alloys

Alloy Type	Liquidus	Pouring Temperature, °F	Superheat, °F
Guy	~2520	2800	280
Inco 700	2530	2800	270
GMR 235	2520	2850	330

Cooling curves of Fig. 1 indicate a gradient of 100°F per in. at the time of solidification, which is the time that demand for feed metal is most important.

Gating Design: A new gating system was designed because the majority of the present systems attempt to deliver molten metal at both ends of the vertically cast bar. This procedure results in the turbulent meeting of two streams of hot metal in the test bar and can lead to unpredictable drossing variations and variable thermal gradients during solidification. The principal reason for this type of gating is to avoid cold riser metal. By contrast, it is generally agreed that a minimum of turbulence is encountered with bottom gating. The General Motors research group[3] has developed a rather elaborate design based on this principle. This mold design, however, still employs an auxiliary runner to avoid cold riser metal. With rapid bottom pouring, a simple bottom gating system was considered possible, and a suitable design was developed.

Fig. 1 indicates that ideal directional solidification with equal feeding from both ends of the test-bar is obtained with this new arrangement. Furthermore, all bars have the same cooling rate because of symmetrical arrangement about the downsprue.

Pouring Temperatures: GMR 235 was used as a model to evaluate pouring temperature effects. Preliminary tests indicated that the influence of temperature was small and that a statistical study of a large sample would be required; this work is now in progress. However, to allow the investigation to proceed to the more significant phases, a pouring temperature of 2850° ±20°F was used for GMR 235 in order to provide satisfactory fluidity and, at the same time, to insure good casting surfaces. Since it has been established that fluidity is a linear function of superheat above the liquidus, other alloys were poured at approximately the same degree of superheat as shown in Table II. These temperatures were maintained for all three nickel base alloys throughout the investigation. Further work to delineate the quantitative effects of pouring temperature, as well as the influence of melting and superheating periods, is now in progress.

Standard Procedures

While substantial changes in mold design were considered important, a good commercial investment practice was adopted as standard. Accordingly, wax patterns and an ethyl-silicate-base investment were used.

Mold Preparation: This process consisted of making wax replicas of the desired final casting, assembling them on a wax gating system, dipcoating the replicas with a thin coating of fine silica slurry, enclosing the assembly in a flask, and finaly pouring in the investment material. To provide proper green strength for handling, the mold was allowed to set up at room temperature prior to dewaxing and firing.

Melting and Pouring: Melting and pouring of the experimental nickel base alloys was conducted under three atmospheric conditions: air, argon-protected, and vacuum plus argon. Melts were made of virgin metals, except as noted in the text.

The crucible charges and order of additions were roughly the same for all three types of atmospheres. Nickel, chromium, cobalt, molybdenum, and iron

Table III. Chemical Analyses

Alloy Type	C	Cr	Mo	Al	Fe	Ti	B	Co	Cb
Guy									
Charged	0.10	13.5	7.0	7.0	4.5	—	0.60	—	2.0
Wide Range	0.08-0.26	12.83-15.35	4.42-5.87	4.33-7.31	4.36-6.94	—	0.28-0.48	—	1.52-2.30
Narrow Range	0.10-0.15	13.08-15.35	4.42-5.87	5.50-6.80	4.64-6.94	—	0.37-0.48	—	1.83-2.30
Inco 700									
Charged	0.10	15.5	3.2	3.5	0.5	2.0	—	29	—
Wide Range	0.09-0.34	14.79-15.89	2.10-3.32	1.32-3.4	0.17-0.99	1.30-3.3	—	27.14-30.5	—
Narrow Range	0.12-0.16	15.03-15.60	2.10-3.03	2.90-3.52	0.37-0.69	1.65-2.10	—	27.7-29	—
GMR 235									
Charged	0.15	15.5	5.0	3.5	10.0	2.0	0.09	—	—
Wide Range	0.15-0.27	15.03-15.99	4.31-5.39	2.37-4.66	7.65-11.10	1.70-2.30	0.06-0.12	—	—
Narrow Range	0.15-0.18	15.03-15.99	4.31-5.39	3.02-3.88	8.54-11.10	1.75-2.30	0.06-0.10	—	—

Effect of Melting and Casting Atmospheres Upon Stress-Rupture Properties at 1500°F.

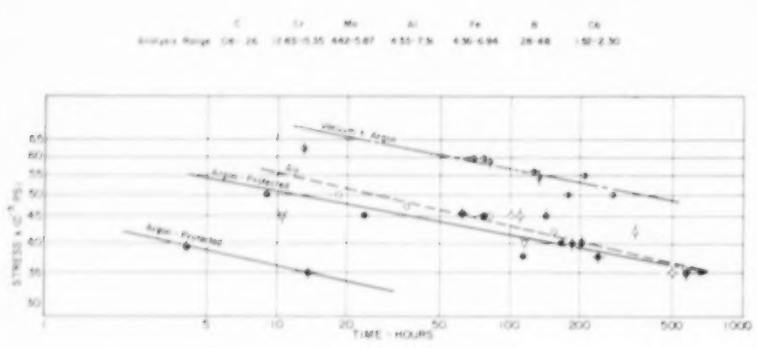


Fig. 4—Guy alloy; wide range analysis. A second curve was drawn for one argon-protected heat here and in Fig. 5, because a foreign white phase appeared in large amounts. See Fig. 10c.

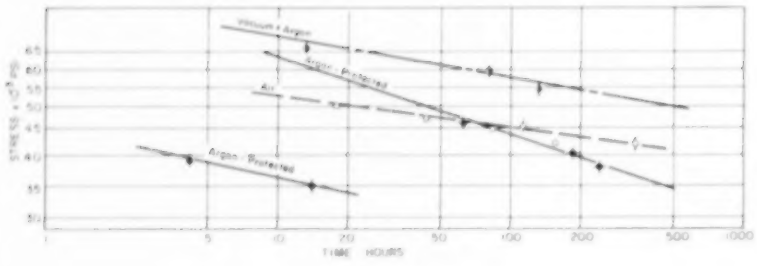


Fig. 5—Guy alloy, narrow range analysis.

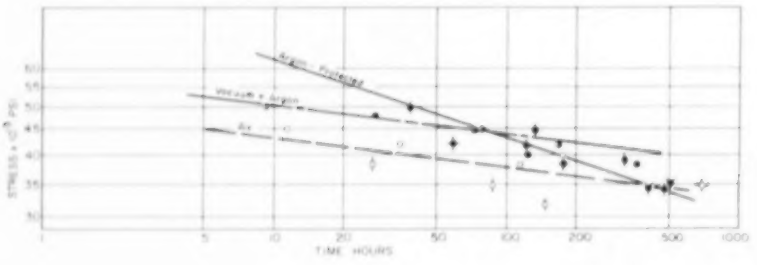


Fig. 6—Inco 700 alloy; wide range analysis. See Figs. 11 and 12 for corresponding microstructures.

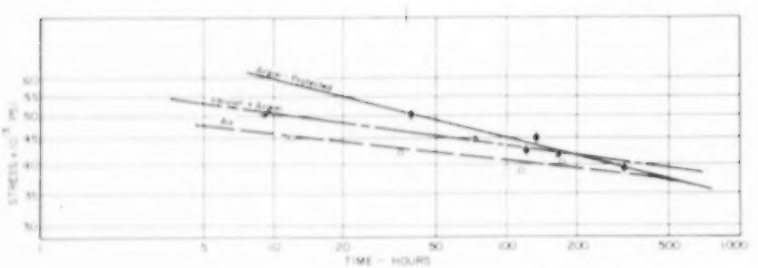


Fig. 7—Inco 700 alloy; narrow range analysis.

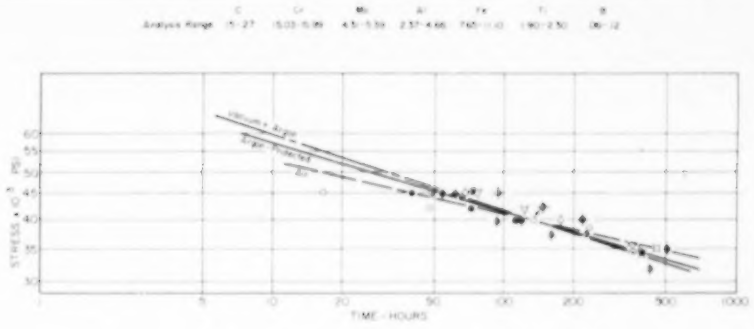


Fig. 8—GMR—235 alloy; wide analysis range. The difference in structure (Fig. 13) and properties is apparently due to the boron content.

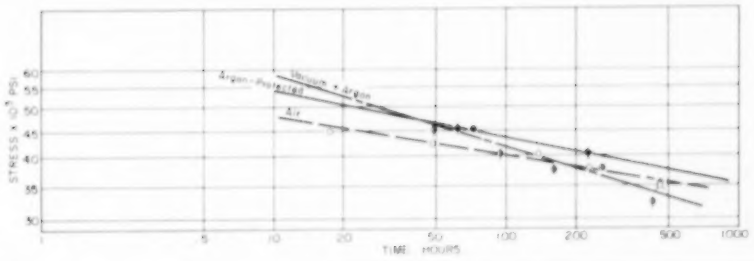


Fig. 9—GMR—235 alloy; narrow range analysis.

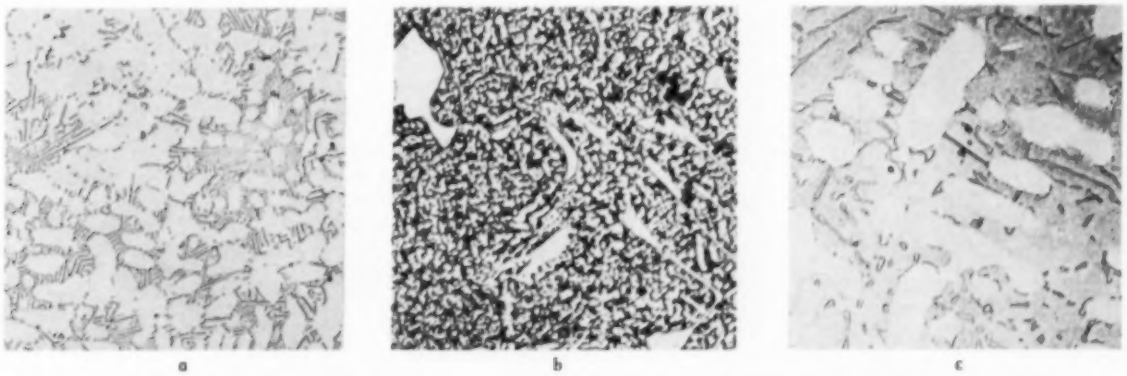
were charged into the crucible. After melt down, other alloying elements were added in the following order: aluminum, carbon, titanium or columbium, and boron. Nickel squares were charged with the aluminum and titanium additions to curb their violent exothermic reactions.

Temperatures for air and argon melting were measured by a Pt-10 pct Rh-Pt thermocouple enclosed by a fused-silica tube. Optical pyrometer measurements were used to follow temperatures in vacuum. Heating rates in air and argon were determined for each alloy at constant kilowatt input. These rates were used to calculate the actual pouring temperature, since the thermocouple had to be removed to place the mold on the furnace. The time between the last temperature reading and pouring was exactly 2 min. Liquidus temperatures were determined for each alloy investigated.

Air Atmosphere: The roll-over induction furnace used both for air and for argon melting is shown in Fig. 2. The mold was clamped on top of the furnace and the assembly rolled 180°. With air melting, the crucible was uncovered, allowing the melt to be exposed. When the heat was poured, the mold was clamped above the furnace and argon pressure was used in pouring. A pressure of 5 psig was applied after the mold had been rolled approximately 90° of the 180° total.

Argon-Protected Atmosphere: The same procedure was followed in argon-protected melting as in air melting, except the melt surface was covered with a blanket of argon throughout the heat. The crucible was charged, covered with an asbestos gasket and refractory brick, and flushed with argon. A positive argon pressure was maintained within the crucible during melting. Argon pressure was again used for pouring.

Vacuum Plus Argon Atmosphere: The mold assembly within the shell, the crucible, addition buckets and dipper are shown in Fig. 3. Pressure within the shell during actual melting was below 5 microns. The crucible was charged, and the buckets were



a b c

Fig. 10—Microstructures of cast Guy-type alloy; electrolytic etch, 5 pct HF, 10 pct glycerine, and 85 pct alcohol. a) general structure, air atmosphere, 100X; b) matrix structure—fine precipitate in matrix is $Ni_3(AlTi)$—air atmosphere, 1000X; c) unidentified white phase in low strength alloy produced in argon protected atmosphere, 500X.

filled with alloy additions; the cover was closed, and a vacuum was drawn. At this point the power was applied to the crucible. After melt down, the heat was held for 20 min at approximately 2700°F to allow refining to take place. After refinement, alloy additions were made.

Since a considerable decrease in mold temperature would occur if the mold were placed in the vacuum shell at the outset of the heat, it was left in the firing furnace until after the alloy additions were made. To protect the melt from air contamination while the mold was inserted, argon was introduced into the shell and the melting crucible covered. After insertion of the mold, another vacuum was applied, and the heat was remelted and heated to the pouring temperature. The operation required 20 to 30 minutes. Argon was bled in during pouring.

Even though the sprue temperature was apparently greater than 1200°F after this period, actual mold-cavity temperature was unknown. A cooling curve from a mold preheated at 1600°F showed that after 30 min the mold-cavity temperature dropped to 900°F. Cooling curves of molds heated at 1800°F indicated that 8 min were available before the mold-cavity temperature fell to 1600°F. To meet this time requirement, the melt was kept liquid during introduction of argon. Power was applied immediately after the mold was inserted and the cover closed. The vacuum was applied to the shell after the power was turned on, and a pressure of 30 microns obtained. Argon pressure of one atmosphere was applied during pouring, as in the previous case. Two heats were made while using this procedure, and a mold temperature of 1600°F was attained at pouring, 8 min after mold withdrawal from the firing temperature of 1800°F.

Chemical Analyses: The chemical ranges of the elements and the percentages charged for the alloys are listed in Table III. Difficulties arose early with Ti, Al, and B analyses. Several checks of these elements were performed by the International Nickel Co.[5] The validity of the low Al, Ti, and B analyses was questioned, especially with the charged percentages listed. However, to check the effect of the analysis spread on the stress-rupture properties, the narrow analysis range was obtained by removing heats which greatly departed from nominal analyses.

Fig. 4, 6, and 8 contain all heats made for the three alloy types, and their wide analysis range is listed in Table III. Figs. 5, 7, and 9 contain heats with the narrow analysis range, also listed in Table III. Composition variations were found to have little effect upon 100-hr rupture strengths of the three alloys. Some small changes occur in the slopes of the stress-rupture lines.

Mechanical Testing: To evaluate the effect of melting and casting atmospheres upon ambient-and elevated-temperature properties, the following were used as indices:

Ambient-Temperature Properties	Elevated-Temperature Properties
1) Tensile strength	1) Stress-rupture strengths at varying rupture times
2) Yield strength (0.2 pct offset)	2) Pct elongation
3) Rc numbers	3) Pct reduction of area
4) Pct elongation	
5) Pct reduction of area	

Before testing, each specimen was radiographed and visually inspected for any flaws, and only those which were radiographically sound and which possessed good surface quality were submitted. The general procedure for room-temperature testing

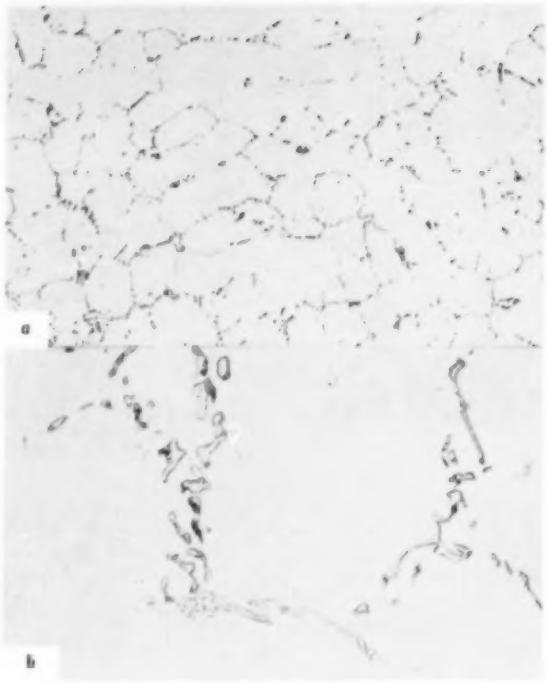


Fig. 11—Microstructures of cast Inco 700-type alloy, etched same as in Fig. 10; a) general structure produced from argon protected atmosphere, 100X; b) detail of precipitate shown in (a), 500X.

Table IV. Effect of Atmosphere on Stress-Rupture Properties of Three Nickel Alloys at 1500°F

Alloy Types	Atmosphere	Rc No. Before Testing	Rc No. After Testing	Stress; Avg per Heat	Rupture Life, Hr; Avg per Heat	Elongation, Pct[1] Avg per Heat	Area Reduction, Pct[2] Avg per Heat
Guy	Argon	38.5	31	35,000	530	2.0	2.0
	Argon	36	40	43,500	62	1.5	3.5
	Argon	43	44	37,000	9.2	2.0	3.0
	Argon	39	31.5	41,000	490	3.3	4.7
	Air	37	30	35,000	513	5.3	7.3
	Air	38.5	33	46,300	73	2.0	2.3
	Air	43	29	43,500	238	3.5	6.0
	Vacuum			57,500	143.5	6.5	13.0
	Vacuum			59,000	75.2	7.0	11.0
	Vacuum			55,000	126.3	5.3	6.7
	Argon			42,500	172	2.0	2.0
	Argon			42,500	123.5	2.0	2.5
	Air			40,000	117	3.0	4.0
	Air			45,000	102	2.0	1.5
GMR 235	Argon	30	29	35,000	306.3	5.7	10.0
	Argon		25	43,500	62	4.5	7.0
	Argon	32	34.5	40,000	238	9.0	14.3
	Argon	33	33	42,500	142	8.5	11.0
	Air	30		35,000	366	11.0	15.0
	Air	31	31.5	35,000	457	8.0	11.0
	Air			42,500	77	3.5	8.5
	Air	32	27	40,300	197.3	9.0	17.0
	Air	32.8	32.5	41,700	144.3	6.3	11.0
	Vacuum	30.5	30	45,000	73	19.0	22.0
	Vacuum	26	32	38,500	183	14.3	29.0
	Vacuum			42,500	116.3	15.0	26.5
Inco 700	Argon	38.5	31	35,000	481	4.0	4.0
	Argon	32.5	28	42,500	121	3.0	5.2
	Argon	31	29	44,000	153	3.7	5.4
	Argon		34.5	38,000	238.3	3.0	4.7
	Air	31	33	35,000	777	7.0	18.0
	Air	31	30	42,300	7.33	2.7	3.0
	Air	27	31	35,000	89	2.7	3.3
	Vacuum	33	37	45,300	82.6	12.2	25.7

[1] Pct elongation in 1 in. measured after fracture.
[2] Pct reduction in area measured after fracture.

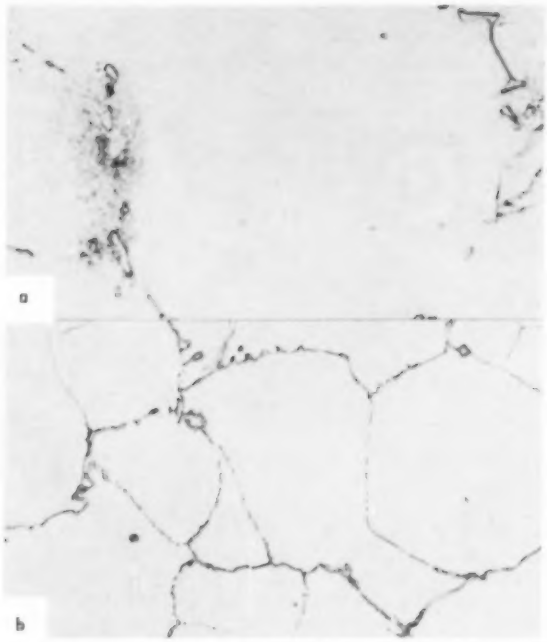


Fig. 12—Microstructures in Inco-700-type alloy after testing at 1500°F; etched as before; a) precipitation around primary precipitate after testing, typical of air and argon protected atmospheres, 500X; b) structure from vacuum plus argon protected heat, 500X.

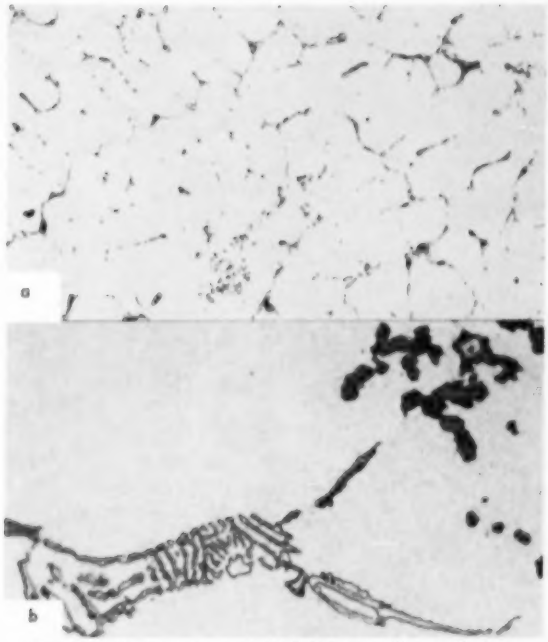


Fig. 13—Microstructures of GMR-235-type alloy, etched as before; a) general structure cast from argon protected atmosphere, clusters of inclusions are TiN plus TiC; eutectic is Ni-B-C, 100X; b) detail of matrix, inclusion cluster and eutectic shown in (a); precipitate in matrix is $Ni_3(AlTi)$; 1000X.

was as follows: 1) the load was applied hydraulically; and 2) strain measurements were recorded by a Martens-type extensometer system. Stress-rupture testing was conducted as follows: 1) three covered thermocouples were tied to the specimen along its gage length; 2) the specimen was placed in a cold furnace and brought to temperature at no load; and 3) the specimen was loaded when the temperature distribution along the gage length was within ±5°F, at 1500°F.

Metallography: All metallographic specimens were taken transversely from the center of the gage length. Electrolytic etching was performed in a solution composed of 5 pct HF, 10 pct glycerine, and 85 pct absolute alcohol. Vacuum-fusion analyses of representative heats of the three alloys melted and cast under the three atmospheres were performed with the National Research Vacuum-Fusion Apparatus at the University of Michigan. Nitrogen, hydrogen, and oxygen contents were determined.

Data and Discussion of Results

The effects of melting and casting atmospheres upon the properties of the Guy, Inco-700, and GMR-235 types of alloys are illustrated in Figs. 4-9 and Table IV. In the sections which follow, the Discussion covers only the elevated-temperature properties because of their importance in design variation with atmosphere. Ambient-temperature properties for all alloys were examined, and no atmosphere effect was evident.

Guy-Type Alloy: In the case of the Guy-type, the elevated-temperature elongation and strength level are raised considerably by vacuum and argon melting, as shown in Table V. A separate curve is drawn for the argon-protected heat in Figs. 4 and 5, because large amounts of a foreign phase appeared in the microstructure. This foreign *white phase* is illustrated in Fig. 10c, and minor amounts were also observed in some other heats. In general, these heats exhibit stress-rupture properties below average for their specific melting conditions. A survey of the analyses does not indicate any correlation with chemical composition. Apparently, the appearance of this phase is undesirable for high-temperature strength.

No optical microstructural changes are evident in the vacuum and argon melted heats to explain the increase in rupture strength or elongation. The structure of this alloy is shown in Fig. 10a. General precipitation occurs throughout the matrix, as shown in Fig. 10b.

Inco-700-Type Alloy: Effect of melting atmospheres upon elevated temperature properties of this alloy is shown in Figs. 6 and 7 and Table IV. Vacuum and argon melting and casting atmospheres exert a significant effect upon elevated-temperature ductility and improve strength somewhat as shown in Table V.

Table V. Effect of Melting and Casting Atmospheres Upon 100-Hr Rupture Strength and Elongation of the Three Alloys at 1500°F

Atmosphere	100-Hr Rupture Strength, psi	Pct Elongation at 100-Hr Rupture
Guy		
Air	42,000	3
Argon-protected	41,000	1-3
Vacuum + argon	56,000	7-10
Inco 700		
Air	37,000	2-4
Argon-protected	42,000	3-4
Vacuum + argon	42,000	21
GMR 235		
Air	41,000	6-9
Argon-protected	41,000	3-7
Vacuum + argon	42,000	14-19

Table VI. Vacuum-Fusion Analyses for Nitrogen

Alloy Type	Heat No.	Melting and Casting Atmosphere	Crucible Temp		Pct N_2 at 1850°C minus Pct N_2 at 1550°C	Pct of 1850°C N Evolved at 1550°C
			1550°C	1850°C		
Guy	R-96	Air	0.0442	0.0154	?	—
	R-98	Argon-protected	0.0098	—	—	—
	R-115	Vacuum + argon	0.0010	0.0021	0.0011	52.
	R-180	Vacuum + argon	0.0029	—	—	—
	R-176	Vacuum + argon	—	0.0036	—	—
Inco-700	R-95	Air	0.0108	—	—	—
	R-117	Argon-protected	0.0045	0.0113	0.0068	60.
	R-109	Vacuum + argon	0.0010	0.0018	0.0008	44.
GMR 235	R-120	Air	0.0043	0.0258	0.0215	83.
	R-99	Argon-protected	0.0053	—	—	—
	R-106	Vacuum + argon	0.0006	0.0025	0.0019	76.
	R-175	Vacuum + argon	—	0.0041	—	—

Oxygen was 0.0003-0.02 pct and hydrogen 0.00008-0.0004 pct at 1850 °C. No consistent variation with type of melting was obtained. The role of dross in the case of oxygen and the role of sample storage time in the case of hydrogen can seriously affect the results.

Optical microstructural examinations give no clues to the reasons for strength or ductility variations with melting and casting atmospheres. The cast microstructure of the Inco-700 type is shown in Fig. 11a. Fig. 11b shows in detail the primary precipitate. This precipitate is probably chromium carbide with dissolved molybdenum and titanium.

Fig. 12a shows the structure of this alloy after testing at 1500°F. This precipitation around existing phases is typical of all air and argon heats. Fig. 12b shows the structure of the vacuum and argon melted Inco-700-type alloy after testing. A radical change has occurred as a result of testing.

GMR-235-Type Alloy: Elongation at 1500°F is strongly affected by melting and casting atmospheres, as indicated in Tables IV and V and in Figs. 8 and 9.

Examination using the light microscope does not explain variations. Fig. 13a shows general microstructure of this alloy. Inclusion clusters are evident. At higher magnifications, Fig. 13b, some of the primary precipitate appears as a eutectic. General precipitation within the matrix is obvious in this figure.

The eutectic is apparently Ni-B or Ni-B-C, since in the Inco-700-type alloy, which has similar chemistry except for boron, no eutectic appears. A similar eutectic also appears in boron steels. Inclusion clusters are titanium carbonitrides.[7] In Fig. 13b, general precipitation is evident in the matrix. This phase is $Ni_3(AlTi)$.[8]

Vacuum-Fusion Analyses—Nitrogen Effect: Vacuum and argon melting and casting decrease the amount of nitrogen in the metal compared with air or argon-protected atmospheres, as shown in Table VI. Apparently, nitrogen may be involved in explaining the marked increases in elongation and strength at 1500°F. Since 1850°C is necessary to decompose TiN or CbN, the difference between the 1850° and 1550°C analyses may indicate the nitrogen combined in this manner. It is interesting to note that the ratio of nitrogen evolved at 1550°C to that evolved at 1850°C is comparable for all atmospheres. Work is in progress to investigate the effect of nitrogen additions to vacuum-melted material.

The vacuum-fusion analyses for Inco-700-type alloys in Table VI show that vacuum and argon melting produces the lowest nitrogen content.

The vacuum-fusion analyses for the GMR-235-type alloy indicate that the increase in elongation at 1500°F by vacuum and argon melting could result from differences in gas content.

Table VII. Summary of Stress-Rupture Properties of the Three Alloys

Alloy Type	Published Properties	This Investigation		
		Air	Argon-Protected	Vacuum + Argon
Guy				
100-hr rupture strength, psi	49,000[1]	42,000	41,000	56,000
Pct elongation, 100 hr	2-5[1]	3	1-3	7-10
Inco 700				
100-hr rupture strength, psi	*43,000[6]	37,000	43,000	42,000
Pct elongation, 100 hr	10*	2-4	3-4	21
GMR 235				
100-hr rupture strength, psi	37-40,000[5]	41,000	41,000	42,000
Pct elongation, 100 hr	6-10	6-9	3-7	14-19

* Solution treated and aged.

Conclusions

A summary of experimental results is presented in Table VII. In all three alloy types, melting under vacuum and casting under argon atmospheres improves ductility two to tenfold under stress-rupture test conditions at 1500°F.

Stress-rupture strength at 1500°F is improved in the Guy-type alloy by 38 pct and in the Inco-700 type by 13 pct with the argon and vacuum melting technique compared with air melting. No change occurs in the GMR-235 type.

The air-melted and argon-protected heats contain from five to ten times the nitrogen of the vacuum and argon heats.

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References

[1] A. G. Guy: Nickel-Base Alloys for High Temperature Applications, *Trans. A.S.M.*, 1949, vol. 41, pp. 125-140.

[2] H. V. Kinsey and M. T. Stewart: Nickel-Aluminum-Molybdenum Alloys for Service at High Temperatures, *Trans. A.S.M.*, 1951, vol. 43, pp. 193-223.

[3] L. B. Pfeil, N. P. Allen, and C. G. Conway: Nickel-Chromium-Titanium Alloys of the Nimonic 80 Type, *Symposium on High Temperature Steels and Alloys for Gas Turbines*, Iron and Steel Institute, 1951, pp. 37-45.

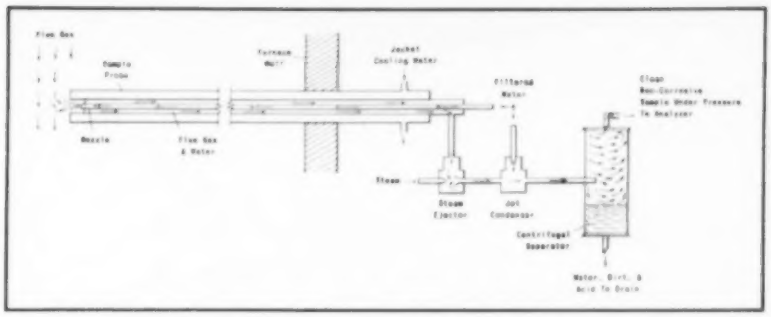
[4] T. Lyman, editor: Metals Handbook 1954 Supplement, *A.S.M.*, 1954, p. 47.

[5] D. C. McCullough, F. J. Webbere, and R. F. Thomson: Improving Investment Casting Quality, American Foundryman, April, 1955, pp. 56-61.

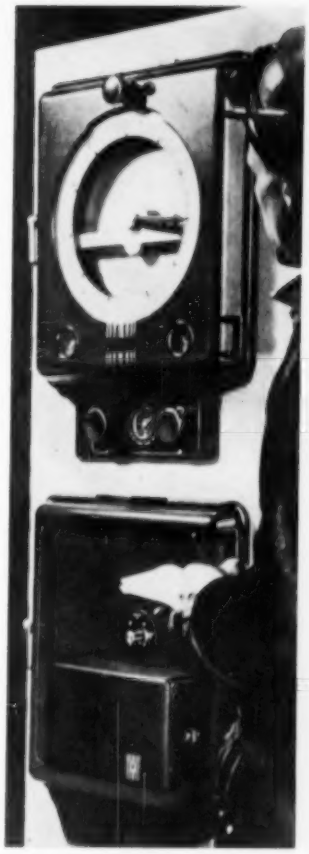
[6] International Nickel Co.: Methods for Chemical Analysis of Nickel and High Nickel Alloys, *Technical Bulletin T-36*.

[7] W. R. Hanne-Rothery, G. V. Raynor, and A. T. Little: On the Carbide and Nitride Particles in Titanium Steels, *Journal of Iron and Steel*, 1942, vol. 145, pp. 129-141.

[8] R. Nordheim and N. J. Grant: *Aging Characteristics of Nickel-Chromium Alloys Hardened with Titanium and Aluminum, AIME*, Journal of Metals Transactions, 1954, vol. 6, pp. 211-218.

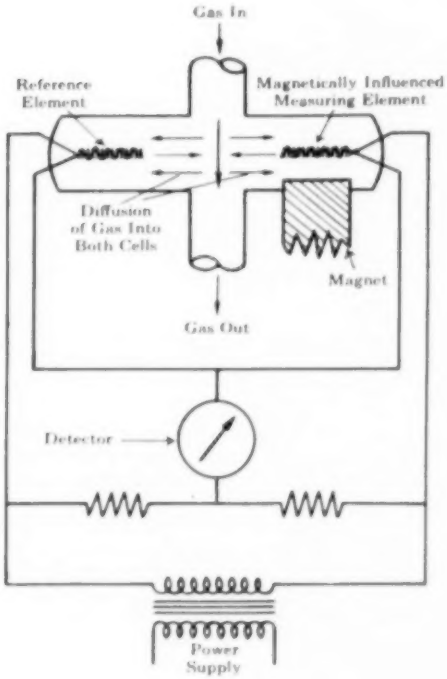


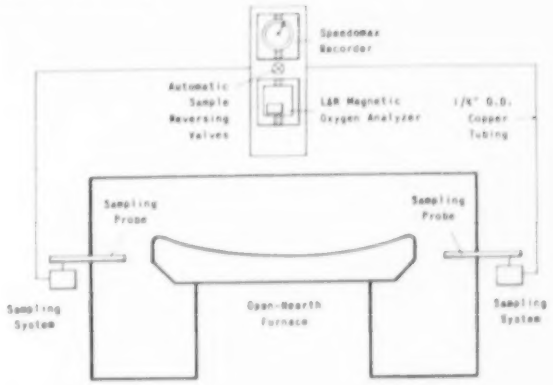
The gas sampling probe, mounted horizontally in the furnace downtake, is a water-jacketed assembly of concentric stainless steel pipes. Continuous washing of the open end prevents clogging by dirt and slag. A portion of the spray water is drawn back between the pipes and is separated out, along with dirt and acid, in a centrifugal separator.



Magnetic Analyzer Gives Better O_2 Samples From Open Hearths

A magnetic oxygen analyzer, developed by the Leeds & Northrup Co. of Philadelphia, promises to give continuous and automatic monitoring of O_2 in open hearth furnaces. Based on the strongly paramagnetic nature of oxygen, the analyzer eliminates auxiliary gas tanks, chemical reactions, and combustion. It is completely contained in the two units shown at the right. The sampling equipment, also designed by L&N, assures a thoroughly scrubbed, acid-free sample which keeps maintenance low by eliminating plugging and corrosion of the sample line.





Above—Schematic diagram showing arrangement of the oxygen analyzer system for open hearth furnaces.

Left—Schematic diagram of the analyzer. A hot wire is suspended in a magnetic field, and when paramagnetic oxygen passes through, a convection current is set up which cools the wire. The strength of this current, the temperature of the wire, and hence the resistance of the wire, all depend on the amount of O_2 passing through the field. This is measured and the device records directly in pct O_2. Other variables, such as changes in barometric or static pressure, are cancelled out by zeroing with the reference cell at the left.

America and the European Coal and Steel Community

WHEN, after long months of negotiation and parliamentary debate, the European Coal and Steel Community (ECSC) came into operation in 1952, there was still doubt in many quarters that the European common market for coal and steel could become a working reality. Now, four years later, with many of the initial problems solved and with the raw materials of European heavy industry moving freely across once insurmountable trade barriers, the skeptics are fewer, but many problems still remain to be solved within the bounds of the Treaty. However, without an extension of the ECSC Treaty into the fields of monetary and fiscal policy, transport, and energy, the market cannot completely operate as does the steel market of the U. S.

The ECSC is second only to the U. S. in steel output. The 1955 ingot production, 52.6 million metric tons, was 26 pct more than 1952, as compared with a 25 pct expansion in U. S. production. Furthermore, production in 1956 is expected to reach 57 million metric tons.

Increased Flow of Steel Products Across National Boundaries

Probably the best test of the success of the European steel market is the movement of steel products across the boundaries of the six countries which make up the Community. This trade, which amounted to 2.1 million metric tons in 1952, has expanded every year since then and reached 5.7 million metric tons in 1955, an increase of 170 pct! The 1952 inter-community trade was only some 5 pct of community production, while the 1955 trade was almost 11 pct of ECSC production. The outstanding point in this trend in trade is the increase in deliveries by works in Belgium, Luxembourg, France, and the Saar to Western Germany.[1]

Relative Price Stability

The competitive forces unleashed by the creation of the European steel market have had a restraining effect on previously widely fluctuating prices in the national markets. There has been a general stability despite the growing tension between supply and demand. Prices charged for basic bessemer steels at the end of March 1956 were, on the whole, much the same as those charged when the ECSC came into being. The prices for open-hearth grades, largely due to higher scrap costs, have increased to a greater extent, but generally less than during previous periods of heavy steel demand.

Coal Demand and Inelastic Supply, A Problem

Increased demands of the steel industry continue to create a strain on the efforts of the Community coal producers to expand production. While coal output has slowly been on the rise, it rarely has matched the demands for coke by ever-hungry blast furnaces. From 1952 to 1955, hard-coal extraction in the ECSC was extended from 238.9 million metric tons to 246.4 million metric tons, almost all of this increase being in Germany and the Saar. During this same period, output per man shift in underground mines increased from 1,389 kg to 1,502 kg. This is a reflection of a heavy investment in the coal mining industry, amounting during these years to roughly $0.50 per metric ton of coal extracted. The discrepancy between increased productivity and production is primarily accounted for by the decreasing number of underground workers, particularly in the Ruhr where collieries lost more than 10,000 between March and September 1955.[1] Losses in manpower are estimated to have cost the Community some 5 million tons of coal in 1955 alone!

The year 1955 was a year of high steel output, but from 1954 to 1955 hard-coal extraction was extended only 2 pct. This was hardly enough to meet demands for coke, and, as a consequence, pithead stocks dropped by more than 5 million tons. The balance of the coal supplies were met by imports from outside the ECSC, and imports increased from 13.9 million metric tons in 1954 to 23.0 million in 1955. Almost 70 pct of these supplies came from the U. S., while the United Kingdom, Poland, and the U.S.S.R. supplied lesser amounts. The bulk of coal imports were destined for German coke ovens, but Italy, a country almost completely dependent upon imported coking coal, also took a large quantity. By drawing upon stocks and utilizing imports, coke production in the ECSC increased by 8.8 million metric tons from 1954 to 1955 to meet an increased pig iron output of 7.9 million metric tons.

During 1956, coal imports are continuing at an increasing rate, and for the first four months over 10 million metric tons of coal were exported from the U. S. to the ECSC.[2] But the Community's coal production is also up, and an additional 2.3 million metric tons were mined during the first seven months.

American Loan Aids Coal Mine Investment

With present coal output unable to cope with the demands of the steel industry and with plans for further extending steel production, there is clearly a need for further investment in coal mines. Of the $100 million loan granted by the Export-Import Bank to the ECSC in April 1954, some $31 million was allocated for coal mine investment, particularly in the Ruhr and Aachen coal fields of Germany.[3] These funds, together with other loans contracted by the High Authority (the executive branch of ECSC) both within and without the Community, and private loans guaranteed by the High Authority of ECSC, will permit a continuation of investment in coal, including the sinking of new shafts in Germany. Furthermore, the High Authority is using funds to aid in financing the building of homes for miners, particularly in the Ruhr valley, thereby tending to increase the permanent coal mining force.

ECSC Steel Capacity Outpaces the Blast Furnace

The long run demand for coking coal by the steel industry would seem to be higher than present consumption figures indicate, for many steel firms, realizing the awkward coal supply situation and seeking to reduce their capital expenditures, have not expanded pig iron capacity sufficiently to meet new steel furnace capacity.

From 1952 through 1955, ECSC pig iron production increased by 6.3 million metric tons, while steel output increased by 10.8 million tons. The pig iron: steel ingot ratio of 0.83 in 1952 decreased to 0.78 in 1955. The High Authority of the Community is encouraging investment in blast furnace capacity, which averaged some $40 million in 1953 and 1954 and increased in 1955.[1] But this is still only some two thirds of the investment in steelmaking furnaces. On the other hand, there has been a heavy investment in sintering plants, which is expected to increase blast furnace productivity and reduce the coke rate.

During 1955, investments created an estimated 2 million tons of sinter capacity, 0.8 million tons of blast furnace capacity, and 1.5 million tons of ingot capacity. It would appear that basic bessemer (thomas) facilities, which normally represent about half of the Community's capacity, are expanding at a slightly greater rate than open hearth capacity. However, the electric furnace process is becoming increasingly popular, and 1955 capacity additions are estimated to be more than a half million tons.

Recent Steel Output Shows More Reliance on Scrap Supplies

Expanding steel output without a comparable pig iron basis puts more reliance upon supplies of ferrous scrap. This may be a good course to follow where scrap supplies exist and the high level of steel demand is considered to be of temporary duration, but where demand appears permanent, then a solid raw material base for steel production should be found.

Prior to 1954, scrap demands by the steel industry of the ECSC were largely met internally. There was a movement of scrap within the Community, amounting to as much as 1 million tons in 1953, largely the result of Italian and German scrap purchases from other member countries.

From 1954 to 1955 ECSC ingot production increased by 8.8 million metric tons, and pig iron output was extended by 7.9 million tons, partially as the result of charging an extra 0.6 million tons of scrap into blast furnaces. The balance of the raw material demands of the steel makers was made up by charging an additional 2.6 million tons of scrap into furnaces. Scrap collections within the Community were stepped up, and increased steel processing itself produced additional scrap supplies in the rolling mills and fabricating plants, but scrap imports from outside the Community were raised from 683,000 metric tons in 1954 to 2,952,000 tons in 1955.[4]

The U. S. was by far the most important supplier, exporting in 1954 some 400,000 tons to the ECSC and in 1955 more than 2 million metric tons. German mills were important customers in both years, and in 1955 Italy accounted for half of these U. S. exports, largely because the Italian steel industry's heavy reliance on scrap which it now found difficult to obtain in sufficient quantities in the French market. Previous to 1954, scrap exports from the U. S. to the countries of the ECSC were insignificant.[4]

Table I. ECSC Iron and Steel Production, Thousands of Metric Tons

Year	Pig Iron	Crude Steel	Basic Bessemer	Acid Bessemer	Open Hearth	Electric
1952	34,702	41,802	23,001	242	15,330	3,168
1953	31,449	39,633	20,882	238	14,885	2,978
1954	33,134	43,838	22,631	190	17,503	3,414
1955	41,088	52,578	27,515	200	20,607	4,145

Sources: Quarterly Bulletin of Steel Statistics for Europe, United Nations, Geneva, Switzerland.

High Authority Asks ECSC Steel Firms to Show Moderation in U. S. Scrap Purchases

Monsieur René Mayer, President of the High Authority of the ECSC, on the 8th of May 1956, said: "As regards short-term measures, the High Authority on a number of occasions approached the American Government to ask that a proportion of the surplus scrap still available in the United States might continue to be imported by the iron and steel industries of the Community. I am pleased to be able to tell you of the understanding attitude taken by the United States Government: I had the opportunity of seeing it for myself when I was there in February. I think I may say that if the industries of the Community continue to show moderation in their scrap purchases from the United States we shall probably not find ourselves deprived of the supplies which are so vital to us, by the introduction of quotas or export restrictions."[4]

ECSC Supervises Scrap Requirements

"The High Authority . . . is . . . exercising constant supervision and discipline over the market by means of a compensation scheme for imported scrap. This system . . . lessens the impact on steel prices of the high price of imported scrap, and at the same time ensures that scrap is imported in sufficient quantities . . . to meet the requirements of the iron and steel industry, and distributed in the Community in accordance with the stock situation."[4]

"The High Authority is now studying . . . a new financial arrangement which . . . will act as a deterrent as regards any disproportionate increase in scrap consumption, by means of a rising scale of levy payments and will thus channel steel production more towards the processes which employ a smaller proportion of this scarce raw material."[4]

Concern in U. S. Over Heavy Scrap Exports

During 1955 and 1956 concern was expressed by steel producers regarding the export of such quantities of a vital raw material like ferrous scrap. Beginning with the second quarter of 1954 the U. S. Dept. of Commerce has made a quarterly determination of policy, in every case refraining from any restrictions. There has been a growing feeling in government that it is vital to our interests to support friendly nations by way of raw materials.

During the spring of 1956, Congress had before it proposals for restriction or prohibition on exports of scrap. The result of this was that Congress directed the Dept. of Commerce to make a survey of available and potential scrap with a preliminary report due Oct. 1 and the final report next Jan. 31. Meanwhile, the Dept. of Commerce is attempting to maintain the status quo pending completion of the survey. The Department apparently would like to see exports held at about the same level as 1955 and, in this connection, has had several meetings with representatives of the ECSC, as well as other major importers of U. S. scrap: Japan and the U. K. The ECSC is attempting through the above cited measures to hold 1956 scrap imports from the U. S. to a little below the 1955 level.[5]

To Solve Long Range Supply Problem
High Authority Seeks Increased Pig Iron Capacity

The President of the High Authority has said that, "The fact remains that if we want to produce more steel with less scrap, we shall have to obtain the iron required from another source—from iron ore by way of pig-iron. The Community's availabilities of iron ore, home and imported, are not, at present, a problem as regards actual tonnage. On the other hand, the capacity of the blast-furnaces, coking-plants and sintering-plants is limited, and this may easily hold up the development of our iron and steel production.

"A year ago, the High Authority announced to the Assembly that it had decided to implement the provisions of . . . the Treaty, concerning the action it is empowered to take in regard to investments, with a view to encouraging the co-ordinated development of capital schemes in the Community."[4]

The Treaty which created the ECSC does not permit the High Authority to insist that certain investments be made or not be made. Enterprises make their own decisions and are responsible for them. The High Authority has, however, many ways of making its influence felt in this field. These include the circulation of general information, issuing opinions on individual investment programs, and the granting of loans and guarantees.

It is now compulsory for enterprises to notify the High Authority in advance of undertaking major investment programs, and—

". . . the High Authority also decided to publish in the *Official Gazette* a full list of its opinions, giving the names and addresses of the enterprises concerned and the investment program to which each opinion relates. In addition, the High Authority has, since 1953, been compiling annual surveys of the capital schemes in progress in the industries of the Community: . . . As in previous years, we have found that the schemes are chiefly for the modernization and expansion of the rolling-mills. This means additional steel requirements, whereas we also find that the extension of blast-furnace capacity is apparently not going ahead as fast as is necessary to increase steel-producing capacity."[4]

In the financial field, the High Authority has continued to help the industries of the Community gain access to capital markets hitherto closed to them, to stimulate Community capital markets, and to bring down loan costs. The High Authority has contracted loans both within and outside of the Community (notably in the U. S. and Switzerland) and reloaned these funds to enterprises or used it to guarantee bank loans. Thus, the ECSC can exercise considerable influence on the course of investment in the coal mining and ferrous metals industries.

Review

While the European Coal and Steel Community is a comparatively new organization, it can be seen that it has already done a great deal to stimulate steel production and consumption by permitting free movement of coal, iron ore, and steel products across the inter-community boundaries.

One of the major problems facing the Community is that of expanding coal production from old mines, over-exploited during the war years, with insufficient investment. Miners, largely dissatisfied with their lot, have been desirous of turning to less arduous jobs. The Community's answer has been: stimulating of investment in mines as well as promoting proper working and housing conditions and the free movement of miners across the borders of member countries.

The coal problem is reflected in blast furnace capacity which has not kept up with expanding capacity of steelmaking furnaces. Scrap supplies have been strained by non-equilibrium conditions between steel and pig iron capacity, and the ECSC has been encouraging investment in blast furnace and coke ovens as well as ore-beneficiating plants.

The U. S. has gone a long way toward making up the deficit in coking coal and scrap supplies. With U. S. coal production at an adequate level this has been welcomed by coal producers, but with scrap there has been some feeling that this valuable raw material should be conserved for our own furnaces. On the other hand, the U. S. has shown itself a friend of the ECSC by continuing to allow the present rate of scrap export, while requesting that it not be increased.

If the ECSC investment in steel plant continues, capacity is expected to be 66.5 million metric tons by 1958. The High Authority is attempting a closer coordination of investment programs so that scrap imports from the U. S. may be expected to show a declining tendency. On the other hand, expanding European coal capacity may continue to be outpaced by steel so that ECSC may be a permanent customer of U. S. coal.

References

[1] *Fourth General Report on the Activities of the Community*, by the High Authority of the European Coal and Steel Community, Luxembourg, Apr. 8, 1956.

[2] Coal Exporters Assn. of the U. S., Inc., Vol. IX, Edition 7, July 17, 1956.

[3] *Yearbook*, Institute of Scrap Iron & Steel, 1956, Washington, D. C.

[4] Speech by Monsieur René Mayer, President of the High Authority, before the Common Assembly of the European Coal and Steel Community, Strasbourg, May 8, 1956.

[5] Communication with the Institute of Scrap Iron & Steel Inc., Washington, D. C.

1949—Increased demand upon smelter capacity met by adding third converter shell, permitting two converters to be kept in constant operation.
1953—New orebody raises demands on smelter; capacity increased on reverbs by new burner setting comprising more units and by increased cross-sectional area of furnace front, and on converters by new arrangement of tuyeres.

Meeting Increased Copper Demand At Magma

Based on an Article by
Edward J. Caldwell

OPERATIONS of the Magma Copper Co. are located at Superior, Pinal County, Arizona, some 67 miles east of Phoenix. Prior to 1924, Magma mine production was shipped to the American Smelting & Refining Co.'s smelter at Hayden, Ariz.; but by this time, the ore's copper content was deemed sufficient to warrant construction of a small smelter. The plant was designed by Bradly, Bruff & Labarthe and constructed by Kansas City Structural Steel Co. It was blown-in on March 29, 1924. As designed, the plant was to have a daily production of 30 tons of blister copper and consisted, in part, of six Nichols-Herreshoff roasters, one 22-ft x 96-ft oil-fired (now gas-fired) reverberatory, and two 12-ft Great Falls converters (one operating and one spare).

During the first few years, blister production matched the designed capacity, but by 1929, increased mine production made a two-converter operation desirable, and a second blowing engine was purchased. During 1945, the concentrator flowsheet was changed over to the production of a direct-smelting concentrate. For the next few years the roaster plant was used only as a drying medium, and in August 1949 the smelting plant was shut down and the charging system was adapted to a wet charge, shutting the roaster plant permanently.

Third Converter Shell Allows Capacity Reverberatory Output

The new concentrator, which had 25 to 30 pct more capacity than its predecessor, was also started up in 1949. This threw added demand upon smelter capacity. Although the reverb was capable of smelting the tonnage required, limitations on such tonnage were set by the quantity of matte the two converters were handling. Brick repairs on the converters were amounting to an average of 4 converter days per month, and it was obvious that lost time would be an outright gain if an extra shell were available. Consequently, a third 12-ft diam Great Falls converter was purchased from the Phelps Dodge Corp. smelter at Clarkdale, Ariz. This spare converter not only did away with lost time due to brick repairs, but also permitted all three converters to be kept in better shape. This placed the converter capacity in step with higher reverb tonnage. The third shell is stored outside the converter aisle on a transfer car. When needed, it is pulled into the aisle by the D4 Caterpillar bulldozer that takes care of the converter aisle clean-up. It can then be picked up by the two overhead cranes operating together. The entire change is accomplished in less than 45 min.

At this time, it appeared that the smelter was in favorable balance with mine production. However, with cessation of zinc mining and milling in September, 1952, all facilities of both mine and mill were devoted to copper production. Increased tonnage was felt at the smelter early in 1953 and prompted a 7-day operation out of what had been a 6-day operation. In addition, production from a new orebody

EDWARD J. CALDWELL is smelter superintendent of Magma Copper Co., Superior, Ariz.

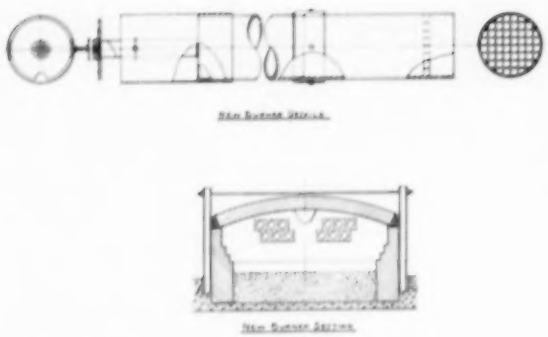


Fig. 1—Detail of modified burners and arrangement in reverb wall.

raised the concentrator heads, thereby making demands for increased smelter capacity.

Increased Reverberatory Capacity Required in 1953

Considerable work was done on reverberatory burner setting in an attempt to increase firing rate and/or combustion efficiency. Burner setting in 1953 consisted of four surface combustion burners made of 8-in. pipe. The venturi throats were cast iron and carried an adjustable damper for control of air inspiration. Three-quarter in. orifices were used, and for a normal firing rate of 80,000 cu ft per hr, a header pressure of 21 lb was required.* These burners operated quite efficiently under normal firing rates, but it was discovered that sufficient primary air could not be inspirated at firing rates above 80,000 cu ft per hr. Thus, at a firing rate of 100,000, secondary air provided by openings in the burner blocks had to be used. This meant that at least 20 pct of the total air required had to be secondary, and this, in turn, gave rise to oxygen-rich and oxygen-deficient zones within the reverb as proven by the coexistence of carbon monoxide and excess oxygen. Firing rates above 100,000 cu ft per hr were impossible because of lack of sufficient furnace cross-section on the front end, near the boiler throats.

With the amount of secondary air required for the higher firing rate, combustion was not efficient, and, what was more serious, complete oxidation of the fuel was far too slow. Orsat readings through the arch, taken at progressively greater distances from the bridgewall, indicated that oxidation was not essentially completed until a point 70 ft from the bridgewall was reached. This position was just ahead of the point where the furnace cross-section was reduced. Readings at this point indicated maximum draft of 0.03 in. of water between charging cycles and 0.05 in. water pressure, or more, during charging. It was found impossible to increase draft at this point by any setting of the boiler dampers, and any increase in firing rate over 100,000 cu ft per hr would result only in large percentages of carbon monoxide in the waste heat boilers.

The necessary conclusions were obvious. What was needed was an entirely new burner setting—a burner setting comprised of more units, or burners, that could successfully and efficiently assimilate the desired volumes of fuel, using close to 100 pct primary air. It should also be capable of firing rates well in excess of 100,000 cu ft per hr if the reverb design could be altered to handle such volumes.

* All gas volumes are in cu ft corrected to 0.630 specific gravity, 60°F and 1,000 BTU per cu ft.

A second conclusion was that if firing rates in excess of 100,000 cu ft per hr were desired, these rates certainly couldn't be obtained with the existing *bottleneck* in the front end of the reverb. This point had a cross-sectional area of only 58 sq ft as compared to an average of 96 sq ft between charge piles in the balance of the reverb. The two boiler throats each had an entrance area of 64 sq ft; so, it was decided to enlarge the 58 sq ft section to the full 96 sq ft that was potentially available. This job was given favorable consideration, since nearly the entire front end needed replacing in any event, and there would be less brick and time involved in the new arrangement. Other than the cost of the new burners, the entire job would cost no more, and probably less, than that which otherwise would have been done and considered within the scope of normal repairs. The reverb was shut down July 16, 1954 to effect the above repairs and changes.

The inside, longitudinal tie-rod on each side of the reverb had to be eliminated, as otherwise this rod would be within the furnace atmosphere when the sidewalls were moved back. The one remaining rod on each side was figured strong enough to carry the tension required to hold the ends during warm-ups.

The steel crossovers into each boiler, under which the longitudinal tie-rods passed, were cut off on the furnace side to conform with the inside of the newly positioned sidewalls. These shortened crossovers contributed an added advantage in that slag deposition thereon should not be as much a problem as formerly.

The excavation for the new sidewalls was taken down to a point 6 in. below the bottom of the buckstays. The new sidewall was constructed of 12 in. of chemically bonded magnesite brick backed-up by 24 in. of silica brick. This thickness was carried up as far as the bottom of the skim door, and it was then corbelled-back 6 in. every fourth course until a 12-in. wall was attained.

The old sidewalls under the boiler crossovers were taken down to the level of the existing furnace bottom at that point, and the void between the old and new walls was filled with a tamped mixture of crushed magnesite brickbats and basic mortar; the old, angled sidewall base was allowed to smelt-out.

New Burner Arrangement Increases Firing Capacity

The burner setting decided upon was adapted to Magma conditions from a setting that was in use at the International Smelting & Refining Co., Miami, Ariz. The burners are made from standard, 8-in. pipe; a grid composed of 1-in. square openings is placed 4 in. back from the discharge end of the burner. The purpose of this grid is to equalize gas velocities across the diameter and insure the proper mixing of gas and primary air.

The gas is fed to the burner through a 7/16-in. diam orifice with tapered approach, and primary air is inspirated through an opening adjustable from 0 to 12 in. by means of a sliding sleeve. This burner detail is shown in Fig. 1. It should be noted that the burner tips (the last 24 in. that contain the grid) are readily changed when necessary, since this portion is held fixed by only four set screws.

Twelve of these burners are used in the new setting and are arranged in two rows of six each across the bridgewall as shown in Fig. 1. The burners are all parallel to the long axis of the reverb; the top row of six are set at a random, vertical angle approximating 10 degrees to keep the flame from scoring the bottom side of the arch at the bridge-

wall. The burner blocks were cast from a chrome castable, which is carried centrally in this tunnel by means of a semicircular strap placed under the burner barrel. The openings between the burner barrel and burner tunnel are closed with a flat, circular strap. Flexible, braided hoses connect the burners to the gas header.

The reverb was fired-up on August 1, 1954, just 15 days from the time the fires were cut off.

It was soon established, that at a header pressure of 47 lb, the burners were firing at a rate of 115,400 cu ft per hr. Oxygen determinations taken directly behind the grid yielded 18.1 pct to 18.4 pct, indicating that the burners were using very close to 100 pct primary air. The burners were living up to expectations, and the widening of the front end indicated, at the above firing rate, that more fuel could be handled. Since the metering equipment is limited to 50 lb, it was impossible to increase gas volumes by increasing pressure, and the installation of larger orifices resulted only in surging by the burners with resultant vibration of the main arch. The 7/16 in. orifice is apparently optimum size for this burner, and the use of a larger one results only in adverse characteristics. Under the new conditions, the reverb was efficiently handling over 15 pct more fuel; so, the burners, like the front end change, were considered justified and successful.

The widened front end gave neutral draft readings during charging and up to 0.05 in. water between charging, the position of the sample tube remaining the same as before the change. At no time, except for matte explosions, have the furnace charge holes been out-cast with flame as they were before, and, as a consequence, the furnace atmosphere is relatively clear without sacrificing draft setting.

Orsat readings indicated that oxidation of the fuel was essentially complete within the first 8 ft from the bridgewall. As a consequence, bridgewall temperatures were running over 2,600°F, or 300°F higher than with the old burner setting. Careful attention to bridgewall fettling was now necessary, but after only 5 months of operation, some corrosion of the bridgewall was observed in spite of continual fettling. At this time, a system of air sprays was installed below the bottom row of burners to aid in the dissipation of the increased heat.

Table I. Magma Copper Co.—Reverberatory Solid Charge

	Charge Make-up, Wt Pct	Analysis, Pct Cu	Fe	CaO	Al_2O_3	SiO_2	S
Concentrate	82.41	25.41	24.0	0.7	1.4	11.5	29.7
Crude Ore	4.07	5.87	11.4	1.1	8.7	53.4	14.6
Secondaries	8.14	22.85	29.9	1.8	3.3	16.9	12.9
Limerock	5.38	—	—	48.5	1.5	5.5	—
Weighted Average		23.04	22.7	3.4	1.9	13.3	26.1
Charge divided as follows:							
Reverb Mix	89.63	23.63	22.5	3.6	1.5	11.7	27.6
Fettling	10.37	17.94	24.6	1.6	4.9	27.4	13.4

Reverb-Converter Product Analysis

Reverberatory Slag	0.41	36.9	3.8	5.8	34.8	
Converter Slag	2.94	51.2	1.6	4.6	23.7	
Matte	34.11	32.8				23.9

Magma Copper Operating Data

Matte fall	67.5 pct
Silicate degree, final slag	1.30
Ratio, converter slag tonnage to final slag	61.8 pct
Total sulfur eliminated in reverb, pct	29.0 pct

With these changes, the reverb not only took up all the slack in the converters, but also the firing rates generally had to be reduced to keep the matte supply in proper balance. So, the problem then became one of increasing converter capacity.

New Converter Tuyere Arrangement Brings Capacity into Balance

The converters were equipped with the conventional Great Falls tuyere line, which consisted of 24 tuyeres, each made of 1½-in. pipe. Air flow measurements indicated that, individually, the converters were utilizing from 6,000 to 9,000 cu ft per min with an average flow of some 7,500 cu ft. The two blowing engines were rated at a total of 20,000 cu ft; so, some 5,000 cu ft were still available.

Adding more tuyeres was out of the question, as there was no room for them. In searching for some means of increasing air consumption, it was discovered that the old United Verde Copper Co., which employed eight or nine of these Great Falls Converters, had used an entirely different tuyere set-up. Their tuyere lines consisted of only 16 tuyeres, but the tuyere pipes were 2-in. Their 16 tuyeres had 38 pct more cross-sectional area than the Magma 24-tuyere set-up. Although operating data were not available, this looked as though it might be the answer.

The wind box was removed from the spare converter; the 24 existing holes were welded up, and 16 new holes were drilled and tapped for 2-in. pipe. These new holes covered the same length of wind box as had the previous 24, but at greater distances or centers.

The tuyere valves, or bodies, were similarly drilled out for a 2-in. windbox connection and a 2-in. tuyere pipe. The tuyere caps, however, did not have sufficient stock to allow for a 2-in. hole; so, the opening was bored out to only 1¾ in., but this was considered sufficient for purposes of the test run.

This converter was placed in service October 16, 1954 alongside the other converters. During the first campaign, the amount of work this converter did, relative to the other, was surprising; average air consumption was about 11,000 cu ft, and peaks would hit 13,000. A total of 18,000 cu ft was now going to the converters and divided between them in the proportions of 11,000 and 7,000 cu ft.

After only a few days of this operation, it was decided that no time should be wasted in changing over the other two converters. New tuyere valves and caps were designed for 2-in. operation; these new castings were essentially the same as were used for 1½-in. tuyeres, although larger all the way through.

In a period of three months, the other two converters were changed-over. With two of these converters in operation, it was found that the total air flow would divide equally between them at about 11,000 cu ft each. Air pressure, with both converters blowing, was 13¾ lb instead of the previous 15 lb.

Results

At the time this report was prepared, the front-end change on the reverb was 15 months old, and the tuyere changeover on the converters was 10 months old. Daily production during this last 10 months, as a result of both changes, is 17 pct higher than the best 10-month period before the change.

From Norway . . .

A New Approach in Electric Pig Iron Smelting

F. C. Collin
O. A. Grytting

● Electric pig iron smelting is well established in such countries as Finland, Italy, Japan, Norway, Sweden, and Switzerland. New plants are being built or have already been put into operation in India, Peru, Spain, Venezuela, and Yugoslavia. The largest furnace units so far developed produce about 200 tons of pig iron per 24 hr. This type of operation is interesting for small and medium sized plants where sufficient electric power is available at reasonable cost and where blast furnace coke is imported.

In covered pig iron furnaces, large quantities of valuable carbon monoxide gas are produced, the heat value of which represents some 1500-2000 kw-hr per ton of pig iron. In many integrated iron and steel plants the gas finds immediate plant application; however, if the gas is used for preheating the charge, possibly with some prereduction of the ore, less electric energy will be needed for pig iron production. The solution to this problem has attracted many investigators, but so far no completely successful method has been developed.

This paper deals with experimental work done at the Research Station of Elektrokemisk A/S at Fiskaa Verk, Kristiansand, South Norway, where a new approach has been made to this interesting problem.

IN a previous paper[1] one of the authors has referred to experimental work in prereduction of iron ore by utilization of Tysland-Hole furnace top gas. Pilot plant tests were made at Christiania Spigerverk in Oslo during World War II, and after the war commercial scale tests were in operation at Norrbottens Järnverk A/B in Lulea, Sweden, in cooperation with Professor Wiberg in Stockholm and Elektrokemisk. Unfortunately these were discontinued. The prereduction tests were done in shaft furnaces, which have the advantage of giving good contact between ore and gas in a counter current flow system. Disadvantages of the shaft furnace are the strict demands regarding charge porosity, and certain technical difficulties with discharge of hot, prereduced ore at the base of the shaft.

The New Approach

Elektrokemisk felt that some inherent difficulties in prereduction might be overcome by use of a rotating kiln. In the above cited experiments with shaft furnaces in Norway and Sweden, prereduced ore was cooled, weighed, and mixed with other components. However, the new plan, as suggested by Professor Durrer of Switzerland,[2] was to utilize the sensible heat in the kiln-treated charge by feeding it hot into the electric furnace. This is comparable to the Sterling process developed by the New Jersey Zinc Co. for electrothermal zinc production.

Production of iron sponge from ore and coke in a rotating kiln has lately been subject to testing by the U. S. Bureau of Mines and Stora Kopparbergs Bergslags A/B of Sweden,[3, 4] but it was not the intent of Elektrokemisk to produce sponge, but only to preheat and prereduce the charge.

The kiln is suitable for handling relatively small sized materials, and the gas pressure drop is negligible. There is little actual contact between gas and charge and thus little indirect reduction from carbon monoxide could be expected. It was proposed to feed to the pretreatment kiln the complete charge, comprising sinter, coke breeze, and fluxes.

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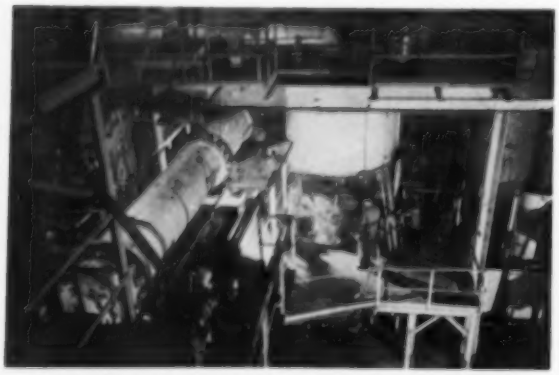

Fig. 1—Pilot plant set-up for electric pig iron smelting. Prereduction kiln is shown in the foreground, with the electric furnace in back.

Experimental Technique

In pilot plant operation, it is important to reproduce correctly the heat balance of commercial pig iron furnaces. After successful application of dimensional analyses and theory of models on electrothermal calcination of anthracite, models of electric smelting furnaces were built in the Elektrokemisk Research Station. The theory for dimensioning such furnaces was developed by Böckman and discussed by him in a previous paper.[5]

The furnace used in pig iron experiments is a scale model of one smelting crater (1/3) of a 7500 kva Elkem pig iron furnace. This experimental furnace reproduces the smelting zones and heat balance of large furnaces surprisingly well. Power consumption per ton of pig iron is in conformity with average consumption figures for large furnaces operated with the same type of raw materials.

In one respect a small furnace operated in this way will differ from a large furnace, viz. not only linear dimensions but also the time is reduced in scale. Consequently, all operations on the small furnace have to be performed according to this reduced time scale. On the other hand, the furnace is more

quickly started up, and any disturbance or change in operational conditions will show its effects faster. In the present test, the time scale is about 1:6, which means that one day's operation of the test furnace is equivalent to about six days operation of the commercial prototype furnace. It is found that 24 hr smelting periods under constant conditions is sufficient to give consistent results.

Pilot Plant

The rotating kiln, purchased from F. L. Smidth & Co. A/S, Copenhagen, continuously feeds the hot, prereduced charge by gravity into the electric smelting furnace. The kiln charge of sintered iron ore, coke, and fluxes is weighed up in batches and filled in the stationary hopper. Below the hopper is a feeder which continuously discharges the raw materials into the kiln through a steel pipe. The charge travels in counter current flow to the hot gases and is discharged through a steel pipe directly into the electric furnace. Gas developed from the final reduction in the electric furnace passes upwards through the same pipe and is burnt with oxygen from air admitted to the kiln.

The experimental electric furnace is a single phase, one electrode, rotating hearth furnace with a stationary water-cooled steel roof. Rate of rotation of the furnace crucible is one revolution per 6 min, which gives an even distribution of the charge around the central electrode from one feed-hole in the roof. High speed of rotation of the furnace greatly simplifies charging as well as observation in the furnace. The charge level in the electric furnace is regulated from the furnace platform instrument panel by changing the rotation speed of the kiln by remote control. The driving shafts of the feeder and kiln are mechanically connected, for a change in rotation speed of the kiln produces a proportional change in feed rate.

Rotation of the smelting furnace is stopped once an hour, the tap hole opened electrically, and iron and slag are tapped in a cast iron mold where a good separation of iron and slag is obtained. After cooling, the slag is knocked off the iron with a sledge hammer, and the products weighed separately. Calculated consumption figures are based on weighed iron.

Table I gives chemical composition of the main raw materials used during the tests. Size of ore and sinter was 0-35 mm, while coal, coke and fluxes were 3-20 mm.

Analyses of iron and slag varied from tapping to tapping, and with such a high rate of smelting it is rather difficult to produce pig iron with a constant silicon content. As the sinter contained TiO_2, it was necessary to use rather acid slags to provide sufficient SiO_2 for high Si-tappings. Very basic slags

Fig. 2—The model electric furnace with top off for cold charging.

caused trouble with TiC-formation in the furnace, while slags on the acid side gave much better separation between iron and slag.

Typical Si-content in the pig iron was 1 to 2 pct, but extreme values of 0.5 and 4 pct were sometimes obtained. The carbon content was 2.5 to 4 pct. Typical slag analysis is: SiO_2 35 pct, TiO_2 10 pct, Al_2O_3 15 pct, CaO 30 pct, MgO 8 pct, and FeO 2 pct.

Due to variations in Si-content of iron, all power consumption figures have been recalculated on the basis of 1 pct Si in the pig iron. The correction used has been 125 kw-hr per metric ton for each 1 pct deviation in Si-content.

Results with Tests with Preheating only

In the first series of tests, mixed charge was heated in the rotating kiln to temperatures between 580 and 850°C. No prereduction of iron oxides in ore or sinter was obtained at these temperatures.

Table II contains some results from operation with the same charge in both cold and preheated conditions. With cold charge the furnace was open as shown in Fig. 2. With the preheated charge a double deck, water cooled roof was used as in Fig. 4. The load on the furnace in this series of tests was from 180 to 280 kw, electrode voltage from 36 to 55 v.

Preheated charge gave a very smooth operation with steady load on the small furnace. Electrical resistance of the charge naturally is lower than for cold charge, but despite this, true arc-resistance smelting conditions were maintained with normal voltage.

Test No. 1 gave a power consumption of 2660 kwhr per metric ton of pig iron for a Norwegian hematite lump ore. In test No. 2 the same charge preheated to 800°C gave a power consumption of 2245 kwhr. Tests Nos. 3-7 showed the same trend in the results for sintered concentrate.

Table I. Analyses of Raw Materials, Pct

Material	Fe	SiO_2	TiO_2	Al_2O_3	CaO	MgO	Fix. C	Vol.	Ash	Degree of Oxidation
Hematite lump-ore (Grindheim)	53.4	9.3	1.1	6.0	2.2	3.3				
Normal sinter (Ardal)	62.3	4.0	3.6	3.3	0.8	1.0				
Normal sinter (Bremanger)	61.8	3.3	2.5	3.4	0.6	1.0				96.5
Lime-sinter (Bremanger)	58.9	3.1	2.2	2.4	5.9	1.2				98.0
Coke-breeze	2.8	6.9		1.8			81.4	4.3	14.3	
Coal							70.9	21.6	7.5	
Semi-coke	1.0	2.7		1.7			79.4	13.5	7.1	

Table II. Comparison of Results of Cold and Preheated Charge

Test No.	Hr of Operation	Ore	Kg of Slag per Ton Iron	Preheating Temp., °C	Consumption per Ton Pig Iron	
					Kw-Hr	Kg Electrodes
1	20.5	Lump ore (Grindheim)	600	cold charge	2660	11.8
2	35.5	Lump ore (Grindheim)	600	800	2245	9.4
3	93.1	Sinter (Ardal)	410	cold charge	2510	13.5
4	71.4	Sinter (Ardal)	410	580	2170	7.8
5	48	Sinter (Ardal)	410	780	2083	11.7
6	97	Sinter (Bremanger)	320	cold charge	2471	10.5
7	48	Sinter (Bremanger)	320	850	2085	9.6

Coke consumption was the same for cold and preheated charge. Electrode consumption is apparently reduced in the same proportion as power consumption. This means that the electrode consumption per kw-hr is fairly constant.

Results from Preheated and Prereduced Charge

Gas available from the electric furnace gave sufficient heat for preheating of the mixed charge to 800 to 900°C. To go a step further and raise the temperature level in the kiln, an oil burner was installed at the discharge end of the kiln.

Solid-state reduction apparently starts at a temperature of about 900°C. Progress of the reaction between coke and iron oxides can be observed from an opening at the discharge end of the kiln, for visible carbon monoxide flames burn on top of the charge where reduction takes place.

Table III presents some results from tests where the maximum charge temperature in the kiln was from 980° to 1050°C. At temperatures above 1050°C the charge softened sufficiently to produce clogging, especially where the flame of the oil burner hit the kiln lining. Load on the electric furnace in these tests was about 180 kw, voltage about 40 v.

Two types of sintered magnetite concentrates were used for the tests, one a normal sinter and the other a so-called lime-sinter, where approximately 10 pct crushed limestone had been added to the concentrate before sintering. In the first series of tests, Nos. 6 to 9, normal sinter was used in combination with gas coke breeze. In the last tests, Nos. 10 to 14, lime-sinter was used in combination with coke breeze, a mixture of 1/3 coal and 2/3 coke breeze, and a low temperature coke (semi-coke).

Power consumption for cold charge, test No. 6, averaged 2471 kw-hr for normal sinter and in test No. 10, 2114 kw-hr for the lime-sinter. Lower power consumption for lime-sinter was due to smaller quantity of slag and to the fact that the limestone was burnt in the sintering process. Also a nearly self-fluxing sinter gave somewhat smoother furnace operation. In tests Nos. 8 and 9, with pretreatment of the charge in the kiln, the maximum kiln temperatures were about 980° and 1050°C, which reduced power consumption to 1728 and 1633 kw-hr respectively.

In tests Nos. 11 to 14 prereduction was carried somewhat further by the use of reducing agents which gave off volatiles in the kiln. Volatiles in coal and semi-coke have actually been active fuels in the kiln, and the temperature level in the middle of the kiln was raised. In this way a greater length of the kiln is utilized for prereduction, and more highly prereduced charge is obtained, despite the fact that maximum temperature was lower than in test No. 9.

The semi-coke, which contained 13 pct volatiles, gave about 100°C higher temperatures in the middle of the kiln, and the degree of oxidation in prereduced sinter was 55 pct. Compared with FeO, which is 66.7 pct oxidized, the value 55 pct implies some reduction to metallic iron. As prereduction has a pronounced effect on power consumption, this was only 1400 kw-hr per ton in test No. 13. In a later test, No. 14, this result was confirmed.

Carbon consumption has varied somewhat from about 260 kg to 390 kg per metric ton of pig iron. For commercial pig iron smelting with cold charge a consumption of 300 to 330 kg of Fix. C is considered as normal.

Table III. Comparison of Results with High Kiln Temperatures

Test No.	Hr of Operation	Charge Make-up	Kg of Slag per Ton Iron	Pct of O_2 in Ore Removed in Kiln	Max. Kiln Temp., °C	Consumption per Ton Pig Iron		
						Kw-Hr	Fix. C	Electrodes, Kg
6	97	Sinter (Bremanger)	320	0	cold charge	2471	315	16.5
8	81	Gas coke breeze	320	13.4	980	1728	296	9.6
9	58		320	17.7	1050	1633	266	10.7
10	60	Lime-sinter (Bremanger)	250	0	cold charge	2114	264	13.2
11	78	Gas coke breeze	250		1000	1625	334	7.6
12	219	Lime-sinter 1/3 coal + 2/3 coke	250	Average 23.0	980	1600	352	10.8
13	90	Lime-sinter	250	41.5	970	1400	353	6.5
14	51	Semi-coke	250		970	1400	390	8.0

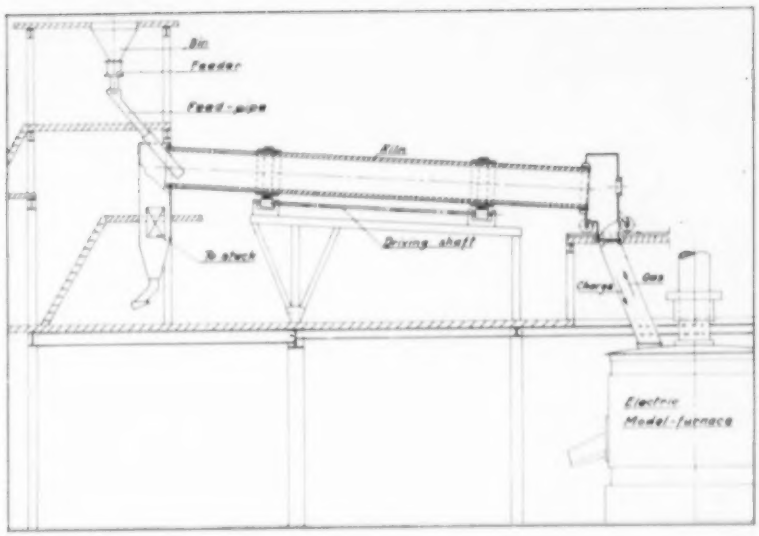

Fig. 3—The pilot plant at the Elektrokemisk Research Station. In the rotating kiln, the charge continuously travels in counter current flow to the hot gases and is discharged through a steel pipe directly into the furnace. The experimental electric furnace is a single phase, one electrode, rotating hearth furnace.

Discussion of Results

Originally, the rotating kiln was intended only for preheating the charge. For prereduction tests the limiting factor proved to be retention time of the charge governed by the size of the kiln.

Reproduction of heat balance of electric smelting furnaces is linked with the reduced time scale of the small furnace and is possible when chemical reactions are sufficiently rapid and therefore not a controlling factor. Temperature distribution as determined by heat conduction seems to be the most important factor.

In the prereduction kiln, however, slow chemical reactions take place, which naturally are of a controlling value to the whole process. In order to reproduce the degree of prereduction, retention time of the charge should be nearly the same in small and large kilns. No reduction of time scale is therefore possible, and the larger ratio of surface area to volume of a small kiln compared with large ones, necessarily gives comparatively larger heat losses for the small kiln. An oil burner had, therefore, to be installed to give sufficient high temperatures for prereduction. This burner was of the short flame type, and gave a rather steep temperature gradient in the discharge end of the kiln. A special type long flame oil burner would have been preferable.

Fig. 4—The model electric furnace with the top on. Note the single electrode and the charging pipe in the foreground.

Addition of semi-coke high in volatiles provided additional heat and raised the temperature level, especially in the central part of the kiln, thus giving a greater length of active prereduction zone. Reactivity of this coke was also high.

Based on F. L. Smidth's calculations for large kilns, it was figured that removal of about 30 pct of the oxygen in the ore and a 50 pct calcination of raw limestone is obtained with 62 pct Fe in the sinter and ordinary coke as reducing agent.

If coal is added as part of the reducing agent or if a semi-coke is used, volatile hydro-carbons are driven off in the kiln, and their heat of combustion is made available for raising the temperature level in the kiln. Combustion of fuel oil or auxiliary gas from a long flame burner has the same effect. With such extra fuel more prereduction may be obtained.

As would be expected, heat losses from the electric smelting furnace are higher for preheated charge. Based on heat balance calculations, it was found that the test results agree with calculated power consumption figures, if a thermal efficiency of 77 pct for cold charge conditions and 72 pct for hot charge was assumed.

The diagram, Fig. 5, gives a graphic representation of calculations for preheating only. The saving in power consumption obviously increases with the quantity of slag. For high grade ore and sinter, preheating to 800°C gives a difference in power consumption of about 15 pct, which means an increase in iron production of 17.5 pct for a fixed power input.

Fig. 6 gives a graphic representation of heat balance calculations for combined preheating and prereduction. Based on the actual test data, the relationship between degree of oxidation and power consumption has been estimated.

For lime-sinter, a power consumption of 1400 kw-hr per ton obtained in two of the tests, compared to 2114 kw-hr for cold charge, was equivalent to 53 pct increase in production for the same power input.

For normal sinter, a power consumption of 2471 kw-hr for cold charge and 1633 kw-hr for pretreated charge, the equivalent increase in production for a fixed power input was 52 pct.

For charge preheated to temperatures below 850°C, tests Nos. 2, 4, 5, and 7, the carbon consumption was the same as for tests Nos. 1, 3 and 6 with cold charge. During these tests with preheating only, no air oxidation of the coke in the charge was noticed.

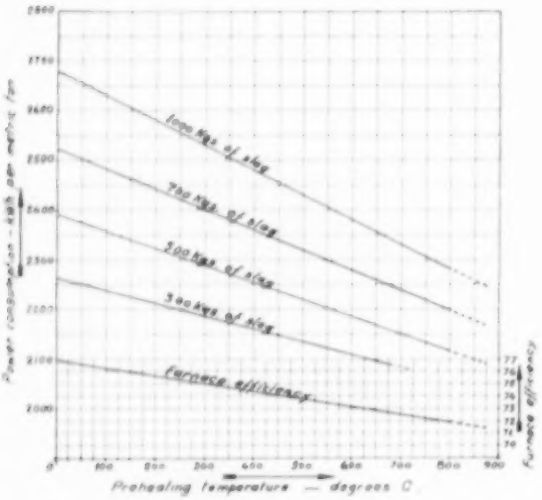

Fig. 5—Heat balance curves for kiln preheating only, showing power saving with increased quantities of slag.

With kiln temperatures of 970° to 1050°C, tests Nos. 8, 9, and 11, coke consumption was not higher than the normal for cold charge. In the tests Nos. 12, 13, and 14, with raw coal and semi-coke in the charge, carbon consumption was from 350 to 380 kg, calculated as Fix. C per ton of pig iron. It is believed that the increase was due to high reactivity of the carbon in these tests, which caused some oxidation by air sucked in through openings in the roof of the small electric furnace.

Scaling Up

For the pilot plant experimental tests a rotating hearth, single phase, model furnace was used. This has greatly simplified transfer of hot charge from the kiln to the electric furnace.[6]

Unfortunately, single phase furnaces are seldom practical for large scale operation. For commercial electric pig iron smelting, three-phase furnaces are generally used, and a suitable charging system for transfer of hot charge has to be developed.

Hot charge is not a new thing in electric smelting. Transfer of hot charge from roasting furnaces and preheating kilns is an established practice in electric copper matte smelting and in electrothermal zinc production. No major difficulties are expected in scaling up the Fiskaa operations to commercial scale, and projects for kiln treatment followed by hot charging are under preparation.

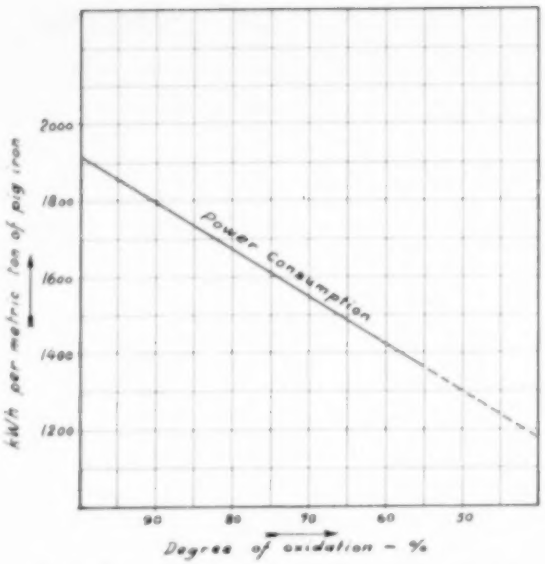

Fig. 6—Heat balance curve for combined kiln preheating and pre-reduction.

Application of the New Practice

The combination of rotating kiln and electric smelting furnace with utilization of carbon monoxide-gas from the reduction of ore, may be applied to old as well as new plants.

By installing a rotating kiln as an addition to a present smelting furnace, it will be possible to increase metal production for a fixed quantity of power. Without increasing the size of the furnace crucible, electrodes, transformers, etc., a 30 to 50 pct higher production is within reach. Despite the fact that fairly large rotating kilns would have to be installed, a substantial saving in production cost is calculated due to reduced power consumption and increased production capacity.

The new practice may offer particular advantages for direct use of bituminous coal in the pig iron process without installation of separate, expensive carbonization plants. The heat value of volatiles in the coal as well as carbon monoxide-gas may be used in the kiln. Many countries have large deposits of iron ore and bituminous coal unsuitable for blast furnace coke production. Where electric power is or can be made available, the combination of rotating kiln and electric furnace will provide a logical solution to pig iron production with direct and full use of fix carbon as well as volatiles in the coal.

Outside the pig iron field there will be interesting possibilities for pretreatment of the charge in the ferroalloy industry. Promising tests have already been made on ferroalloy-production.

References

[1] F. C. Collin: Features from the development of electric pig iron smelting. III Congres International d'electrothermie. Paris 18 to 23 May 1953. Vol I, sec. I, pp. 57-65.

[2] R. Durrer: Electric smelting. *Journal of the Iron and Steel Institute* 1947, vol. 156, p. 260.

[3] E. P. Barrett: Sponge iron and direct-iron processes. U. S. Dept. of the Interior; *U. S. Bureau of Mines, Bulletin* No. 519.

[4] Bo Kalling and Folke Johansson: En metod för reduktion av jernmalm utan smältning i roterande ugn. *Jernkontorets annaler*, 1954, vol. 138, pp. 253-270.

[5] O. C. Böckman: Some experiments with scale models of electrothermic furnaces. *Journal of The Electrochemical Society*, 1954, vol. 101, pp. 493-496.

[6] U. S. Patent No. 2,694,097. Elektrokemisk A/S.

Modernization of Bunker Hill Presintering Practices

by Harold E. Lee and Donald Ingvoldstad

Charge storage and proportioning plant showing air conditioned tunnel in which the sinter charge is composited.

AT Bunker Hill the original charge storage and preparation system was installed in 1917 to accommodate lead-silver gravity mill products. Only minor tonnages of wet fines such as vanner and flotation concentrates were received. Charge flux and diluent requirements were provided by an ample supply of siderite middlings and coarse limerock. While oversize material was crushed through ¼-in., the use of roll crushers in series resulted in a more or less granular, free-running charge of adequate porosity. Under such conditions, receipts could be proportioned directly from receiving bins, and suitable blending was obtained by passing the resultant layered composite through a small Stedman disintegrator.

This elementary system served well for production and smelting of an extremely lead-rich sinter, in the low column blast furnace. Here sinter physical quality is less critical, and appreciable quantities of raw flux and oxidized ore may be charged directly to the blast furnace without seriously impairing furnace capacity.

Prior to 1938 the relative proportions of zinc receipts were low and extraneous flux requirements at a minimum. However, subsequent war-inflated zinc demands brought marked increase in fine concentrate and slimy zinc leach residue receipts and an abrupt introduction to smelting a more refractory zinciferous charge. The higher temperature demands of the more refractory zinciferous charge required a higher smelting column and the higher column, in turn, rendered the blast furnace less receptive to improperly prepared feed. Inadequate presinter processing facilities prevented the production of acceptable sinter, and blast furnace production declined to 50 pct of former capacity.

In view of a prevailing contention among lead metallurgists as to the deleterious action of high zinc slag on blast furnace capacity, it was natural to overstress this factor and to concentrate on possible changes in furnace design. Another interpretation was that primary correction should be sought through expanded sintering facilities. This divergence of opinion, together with the extreme material shortages of the 1940's, delayed corrective

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The Transactions papers appearing in the JOURNAL OF METALS *during 1956 will subsequently appear in AIME Transactions Volume 206, and may be permanently referenced to that volume.*

Table I. Comparative Lead Blast Smelting Data

Plant and Conditions	Slag Type		Charge, Tons per Day*	Σ FeO + CaO + ZnO	FeO: CaO Ratio	Acidity Data		Relative Acidity
	Ingredient	Pct				Metal-Oxide	Oxygen	
Plant A	SiO_2	23.1				SiO_2	12.31	
Tuyere area, 48x100 in.	FeO	30.1				FeO	6.71	
Column 15 ft, blast 46 oz	CaO	21.8	635	66.3	1.4	CaO	6.21	0.44
Charge Pb content: 32 pct	ZnO	14.4				ZnO	2.84	
	RO	10.6				Σ	28.07	
Plant B	SiO_2	22.5				SiO_2	12.53	
Tuyere area, 48x180 in.	FeO	37.5				FeO	8.36	
Column 15 ft, blast 40 oz	CaO	20.5	625	66.4	1.8	CaO	5.84	0.44
Charge Pb content: 36 pct	ZnO	8.4				ZnO	1.65	
	RO	10.1				Σ	28.38	
Plant C-1	SiO_2	29.8				SiO_2	15.88	
Tuyere area, 52x180 in.	FeO	31.5				FeO	7.02	
Column 14 ft, blast 45 oz	CaO	20.2	450	60.1	1.6	CaO	5.76	0.52
Charge Pb content: 38 pct	ZnO	8.4				Zno	1.65	
	RO	10.1				Σ	30.31	
Plant C-2	SiO_2	23.5				SiO_2	11.99	
Tuyere area, 52x180 in.	FeO	31.9				FeO	7.11	
Column 15 ft, blast 47 oz	CaO	16.3	587	65.4	1.9	CaO	4.65	0.44
Charge Pb content: 30 pct	ZnO	17.2				ZnO	3.39	
	RO	12.1				Σ	27.14	
Plant C-3	SiO_2	21.6				SiO_2	11.51	
Tuyere area, 52x180 in.	FeO	29.4				FeO	6.56	
Column 14 ft, blast 47 oz	CaO	14.7	555	65.5	2.0	CaO	4.19	0.43
Charge lead content: ?	ZnO	21.4				ZnO	4.27	
	RO	12.9				Σ	26.53	
Plant D	SiO_2	26.4				SiO_2	14.07	
Tuyere area, 48x180 + in.	FeO	30.2				FeO	6.73	
Column 19 ft, blast 39 oz	CaO	22.4	284	60.1	1.3	CaO	6.38	0.49
Charge lead content: 25.4 pct	ZnO	7.5				ZnO	1.48	
	RO	13.5				Σ	28.66	
Plant D-1	SiO_2	25.8				SiO_2	13.75	
Tuyere area, 48x180 + in.	FeO	30.5				FeO	6.85	
Column 19 ft, blast 42 oz	CaO	21.6	317	61.5	1.4	CaO	6.16	0.48
Charge lead content: 21.5 pct	ZnO	9.4				ZnO	1.85	
	RO	12.7				Σ	28.61	
Plant E	SiO_2	19.5				SiO_2	10.39	
Tuyere area, 48x180 in.	FeO	37.8				FeO	8.43	
Column 13 ft, blast 36 oz	CaO	8.2	300	67.3	4.6	CaO	2.34	0.41
Charge lead content: 37 pct	ZnO	21.3				ZnO	4.20	
	RO	13.2				Σ	25.36	
Bunker Hill smelter, September 1937	SiO_2	22.5				SiO_2	11.99	
Tuyere area, 66x252 in.	FeO	36.0				FeO	8.03	
Column 7 ft, blast 20.5 oz	CaO	15.1	609	67.1	2.4	CaO	4.30	0.44
Charge lead content: 46 pct	ZnO	16.0				ZnO	3.15	
	RO	10.4				Σ	27.47	
Bunker Hill smelter, August 1940	SiO_2	25.2				SiO_2	13.43	
Tuyere area, 66x252 in.	FeO	30.3				FeO	6.76	
Column 7 ft, blast 16.5 oz	CaO	13.0	379	59.6	2.3	CaO	3.71	0.50
Charge lead content: 46 pct	ZnO	16.3				ZnO	3.21	
	RO	15.2				Σ	27.11	

* Monthly or longer period averages.

procedure. During this period, however, operational data from many sources were assembled and analyzed.

Table I is a comparative summary extracted from this smelting data. It will be seen from this table that slag zinc content alone is not critical, but the type of slag in other respects is indicated to be of primary importance in controlling blast furnace capacity. In fact, assuming the charge to be predominantly sinter of proper FeO:CaO ratio[3] and containing minor residual (RO) compounds ranging from 10 to 12 pct (thus the balance silica) a simple rule for attaining high blast furnace capacity appears to demand a slag in which the Σ of FeO + CaO + ZnO approaches 66 pct. This rule presupposes that all slag forming ingredients and proper sulfur diluents exist intimately incorporated in the sinter plant feed and that the composite presinter charge has been endowed with adequate porosity. Under such conditions, fast smelting sinter will follow.

In the period 1948–1949, extensive laboratory experiments were conducted not only to determine related overall smelting requirements, but also to select the most promising alternative procedures. After all conclusions drawn were checked by actual pilot plant operations, 1949–1950, chemical and physical presinter charge control was proved to be mandatory.

To attain such control at a custom smelter subject to long periods of adverse weather and dependent on coarse flux and a wide variety of ore receipts necessitated:

1) An all-weather system.

2) Facilities for crushing all oversize materials to −¼-in.

3) Enough bins—designed to permit positive flow—to maintain adequate segregation of charge ingredients.

4) Provisions to obtain presinter analysis of the composite charge and a means of correcting indicated deficiencies.

5) Adequate charge blending and pelletizing facilities.

It was not economically feasible to realize the foregoing requirements by renovating the existing system, and construction of a new plant was decided upon. This new plant, designed and constructed under contract by Stearns-Roger Mfg. Co., is comprised of four distinct units: a crushing plant; a storage, proportioning, and blending plant; a bedding plant; and a pelletizing plant. Construction was started in the fall of 1951 and completed in October 1953. The initial crushing plant unit was finished and placed in operation in September 1952.

Crushing Plant: The crushing plant was molded into limited space of not too desirable contour. As shown in Fig. 1, it is designed for flexible, multi-

purpose service. It is utilized for: 1) crushing and grinding, to −¼-in., minor volumes of crude ores and major tonnages of charge diluents, fluxes, and circulating byproducts; 2) intermediate reduction and sizing of both finished byproducts and pallet dressing which is required for *one-pass* sintering. As far as dry crushing is concerned, the design is unique in employing a rod mill and including a dryer in the circuit. It will be noted that provisions are made for bypassing both dryer and rod mill and for delivery of products to variable destinations.

Crushing plant feed is received through ten railroad bins of 2600-cu ft capacity, one of which feeds direct to the dryer for the processing of wet slimy materials not amenable to passage through the more devious coarse crushing system. The remaining nine bins feed through chutes with arc gates onto a mobile apron feeder which regulates the flow via belt conveyor to the coarse crushing section.

Primary crushing is accomplished in a Traylor 30x36-in. type H jaw crusher. However, the feed opening of this unit is restricted to 24x36 in. to accommodate tough furnace products such as matte and speiss. Jaw motion is ¾ in. and a minimum open setting of 2½ in. is used.

The −2½-in. jaw crusher discharge is delivered to an Allis-Chalmers No. 648 Hydrocone crusher, which operates in open circuit with a 4x8-ft (½-in. openings) ac rod deck screen. The −¾-in. product of this secondary crushing circuit is conveyed to a Jeffrey continuous bucket elevator 77 ft high, the discharge of which (sampled if desired by a Geary-Jennings sampler) can be diverted to multiple destinations by means of a three-way splitter utilized in conjunction with two reversible belt conveyors:

1) One of the above splitter legs delivers −¾-in. sinter to a 4x8-ft Nordberg Symons rod deck screen with ¼-in. openings. Oversize is returned to the sinter plant for pallet dressing and undersize is belt conveyed to storage in the proportioning plant for use as a sulfur diluent.

2) A second splitter leg, via reversible conveyor, is employed to bypass the rod mill completely (either to the proportioning mill or to railroad cars) and to deliver material of excessive moisture content to an 8x60-ft Stearns-Rogers oil-fired rotary dryer before it goes to the rod mill. This dryer operates on a ¼-in. per ft slope and is driven at 4.45 rpm by a 75-hp motor. The vented dryer gas is cleaned in a No. 24 type N Rotoclone equipped with an Esperanza-type slime remover. The slime is dewatered for circulation along with similar plant products and the clean gas exhausted through a 3-ft diam steel stack by means of a No. 80 Norblo fan. The dryer discharge, by means of a heat-resistant conveyor system, may bypass the rod mill or be delivered to it.

3) The predominant flow of rod mill feed passes through the third splitter leg to a reversible conveyor which feeds either of two steel bins, 12 ft OD by 17 ft high. From these surge bins the rod mill flow is regulated by variable speed feeders.

Because predesign tests demonstrated its efficient open circuit delivery of a −¼-in. product from a range of feed types containing up to 2 or 3 pct moisture, rod milling was selected in preference to the usual closed circuit roll crushing. A 9x12-ft Allis-Chalmers peripheral discharge dry rod mill is employed. This mill is fed by an 18-in. diam, 70-rpm, 5-hp screw feeder and is driven at 17.2 rpm by a 450-hp synchronous motor. Lorain liners 2½ in. thick are employed and a 25 to 30-ton rod load is maintained by the periodic addition of 3½-in. rods.

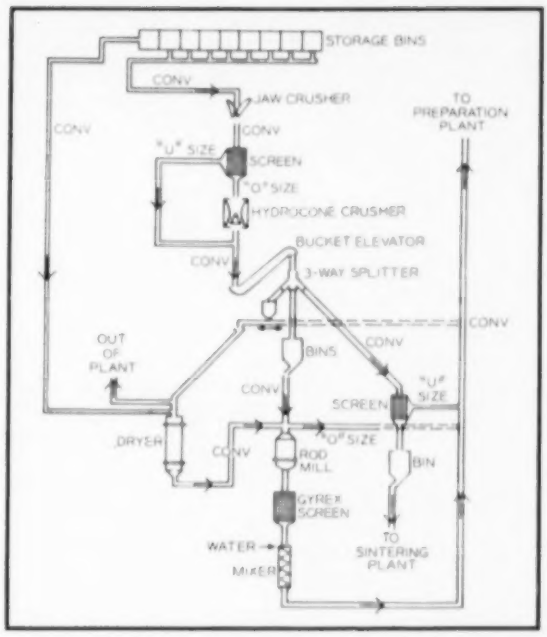

Fig. 1—Crushing building at the Bunker Hill Co. charge preparation plant.

Dry rod mill performance to date has been very satisfactory. After three years of operation, the original liners are still in service and the lifters have only recently been replaced. About once a month, broken rods are removed and 15 to 20 new rods added. Table II presents feed and discharge sizes when the rod mill is operating on two different types of feed at a capacity of about 60 tph.

The rod mill discharge passes successively to a 36x54-in. Robins Gyrex screen (1 mesh) for scalping out broken rods and a Jeffrey double paddle mixer (12 ft long by 3 ft 11 in. wide) for wetting to prevent excessive dusting before it is belt conveyed to the proportioning plant.

All conveyors are interlocked and a dust collection system serves transfer points as well as crushing and screening equipment. The dust-laden air is filtered through an Aeroturn dust collector containing 24 wool felt bags, 18-in. diam by 18 ft long. A size 80 Norblo exhaust fan driven at 800 rpm by a 60-hp motor vents 25,000 cfm through this unit.

As already indicated, this plant reduces a wide variety of products. For operation on large tonnage, including flux and diluent requirements (limerock, slag, and sinter), an average rate of 55 tph is maintained. For processing smaller tonnages of variable

Table II. Dry Rod Mill Grinding Performance

Mesh	Feed, Pct*	Discharge, Pct*	Feed, Pct†	Discharge, Pct†
+2	50.9	0.0	69.1	0.0
+4	30.0	0.8	15.3	0.8
+8	10.1	15.7	5.9	9.0
+14	4.0	24.5	3.2	21.0
+28	1.8	18.7	1.8	16.5
+100	1.6	22.0	3.0	17.8
+200	0.3	6.8	0.5	8.3
−200	1.3	11.5	2.2	26.6

* −¾-in. dump slag at 61.3 tph; rod load 30 tons.
† −¾-in. limerock at 57.3 tph; rod load 30 tons.

circulating byproducts, average capacity is obviously reduced by time lost in switching from one material to another. Depending on tonnage, two to three shifts per day are required with a three-man operating crew. One extra clean-up man is employed on day shift.

Charge Storage and Proportioning Section: Immediately south of the new plant, adjacent to the railroad bins already mentioned, 17 additional bins receive fine concentrate and leach residue shipments. Starting with these receiving bins and picking up the crushing plant load from the east, Fig. 2 traces the material flow through the storage and proportioning section.

A 64x288-ft building houses this section. Along the east wall are 11 concrete bins for storage of crushed fluxes, diluents, and circulating byproducts. Five of these bins are of 7000-cu ft capacity and six of 3500-cu ft capacity. Eight 7000-cu ft bins along the opposite western wall store fine receipts which bypass the crushing plant. Parallel between these bordering storage bins are 19 steel proportioning hoppers of 1000-cu ft capacity. Material transfer from storage to the hoppers is accomplished with a 2-yd Blaw Knox clamshell bucket operated from a P&H overhead crane with 61-ft span. The hoppered proportioning bins are spanned by a steel rail grizzly system which is utilized for bucket cleaning and for breaking compacted lumps. The grizzly rail spacing varies from 6 to 18 in., depending on the character of the material being handled.

The segregation of incoming flux, diluents, and circulating byproducts is obvious. According to the type of slag-forming ingredients they contain, incoming ores are segregated into five classifications. Variations in composition of materials drawn from storage are minimized by provision of adequate bin capacity and by the practice of bedding the flow into storage. Incoming flow is diverted to its proper storage bin by a Robins motor-actuated wing tripper. A selector switch is used to locate the tripper, and bedding of the discharge is effected by an oscillating tripper movement between limit switches.

In an air-conditioned tunnel beneath the central proportioning hoppers, a composite charge is formed by controlled mechanical discharge of the 19 products contained. One of these bins, utilized for very low feed rates, is screw discharged. All other bins employ 4x8-ft pan feeders, of which six are ratchet driven and 12 have a variable speed continuous drive. Feed rates are controlled by adjustments of both gate openings and pan speeds. Gobbing of the pan discharge onto the collection belt is minimized by use of a hinge-mounted solid flight screw, which contacts and cuts the face of the discharge ribbon.

All proportioning hoppers discharge onto a 30-in. gathering conveyor that spills to a cross-belt for delivery to a Pennsylvania, size CF-7-38, reversible impactor driven at 800 rpm by a 200-hp motor. Overall flow rate is limited by the impactor capacity of about 200 tph. In view of this limitation, ores are proportioned on the basis of receipts, circulating byproducts in accordance with production rates, and fluxes and diluents on the basis of metallurgical requirements. Between 5 and 10 pct of estimated flux and diluent requirements is purposely withheld at this stage to facilitate control in subsequent charge correction operations.

In passage through the impactor, ingredient lumps are broken and very effective blending is accomplished. The blended flow is conveyed over a Merrick Model E Weightometer and Rateograph, thence to a two-stage bucket-type sampler before being diverted to the bedding plant.

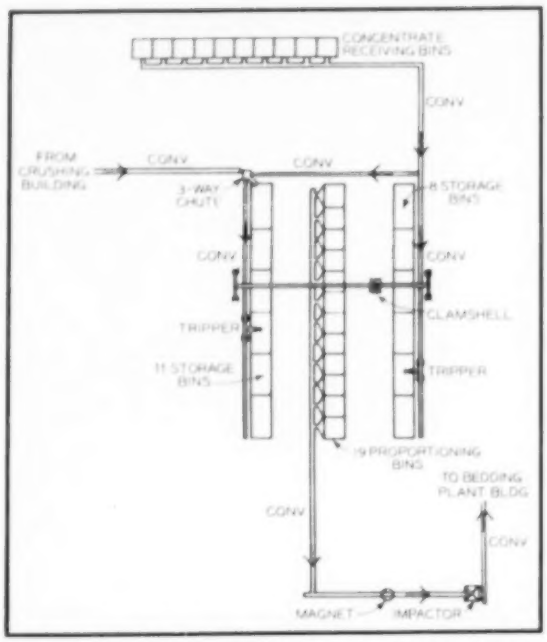

Fig. 2—Preparation building at the Bunker Hill Co. charge preparation plant.

Three operators and one clean-up man, working one shift per day, composite, blend, and correct the 24-hr requirement of 1500 tons. The three operators, all crane men, rotate between the crane, feeder floor, and conveyor stations. The use of small, separate, free-flowing proportioning hoppers originated in Port Pirie practice and was later adopted by the American Smelting & Refining Co. plant at Helena, Mont. It is very effective in obtaining low-cost positive movement of sticky concentrate and slimy residue receipts. Materials compacted in storage are broken and fluffed during transfer from storage to the proportioning hoppers. These hoppers are shallow enough to minimize further packing and the feeders are wide enough to discourage arching.

Bedding Section: In addition to providing a desirable weatherized storage of blended charge, the bedding section is the key to positive metallurgical control. As outlined above, the composite flow is weighed and sampled before being bedded. On the basis of known weight and analysis, each bed is metallurgically corrected, before reclaiming, to target sintering and blast furnace requirements.

The 64x192-ft bedding section floor area accommodates four 925-ton bedding piles. As may be seen from Fig. 3, this area is divided longitudinally by a collection conveyor that operates sublevel in a central trench. Beds are laid around this trench, counter clockwise, by means of overhead trippers operating from belts that span each side of the building. The trippers are spotted by selector switches and oscillate over the bed length between limit switches.

As was mentioned previously, the bedding and correction of 24-hr sinter plant requirements is completed in a single 8-hr shift. Normally, one bed is being laid while a second is delayed awaiting assay. A third bed is either ready for, or in the process of, metallurgical correction (accomplished

usually at the start or close of a shift, . .y the proportioning plant crew over the regular belt system), and the fourth bed is being reclaimed.

Bedding piles are reclaimed at a rate of 175 to 200 tph and the operation is practically automatic. The reclaimer is interlocked with a pressure switch that stops the unit when the pelletizer surge bin is full. As a safety measure, starting is manual. The reclaimer, of Stearns-Roger—Bunker Hill design, operates counter clockwise in an orbit about the collection trench from overhead rails. This unit consists of a mobile, triangular, multitoothed, reciprocating harrow coupled to a drag conveyor. It eats into and excavates the beds at right angles to their formation. The reciprocating harrow, set at the angle of slope, continuously loosens material on the face which slides into the drag conveyor and is carried into the collection trench. Forward motion of the reclaimer is automatic and intermittent, being controlled through a switch actuated by a *feeler* located just above the drag.

Reclaimed material is delivered by the collection conveyor to a surge bin at the head of the pelletizing section. Pelletizing, and thus obviously reclaiming, is on a two-shift basis. One part-time man per shift is required.

Pelletizing Section: In the pelletizing section the sinter charge is endowed with porosity. This desirable physical conditioning in preparation for sintering, though successfully employed in zinc operations, has long been neglected by lead metallurgists. As indicated by Fig. 4, the reclaimed, corrected charge is fed from a 100-ton surge bin by a 4x10-ft Jeffrey feeder into the pelletizing circuit. Pelletizing is usually accomplished (two-shift basis) with a two-man crew at the rate of 110 to 120 tph—the reclaimer operator aids in this operation.

Feed flow is initially conditioned with water in a 5x9-ft A.O.R. pugmill rotating at 6.5 rpm. Moisture addition is controlled manually from an observation point at the subsequent pelletizer drum discharge. Here a flowmeter is provided for re-establishing conditions after shutdowns.

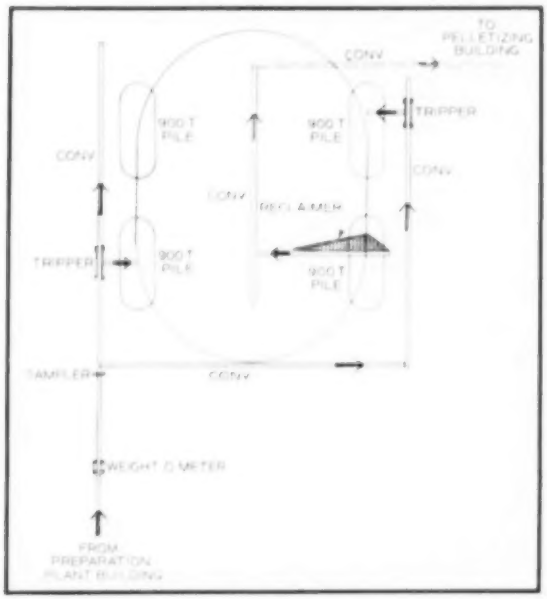

Fig. 3—Bedding plant building at the Bunker Hill Co. charge preparation plant.

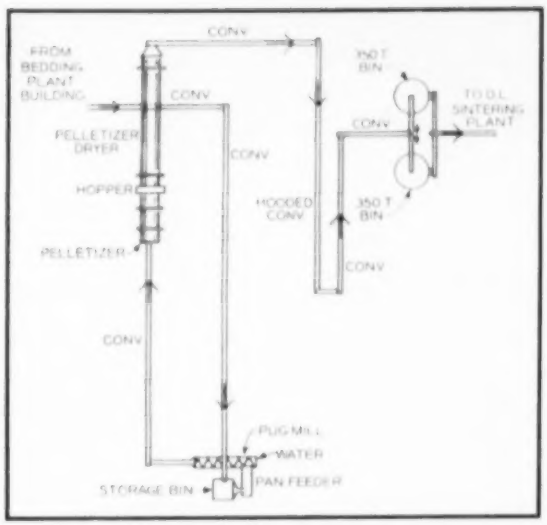

Fig. 4—Pelletizing building at Bunker Hill Co. charge preparation plant.

Flow from the pugmill is advanced to a 8x15-ft rotary pelletizer, which operates at 9 rpm and a slope of 4 in. over its 15-ft length. Build-up on the drum surface is limited to about 2 in. by a rotary cleaner consisting of a pipe shaft into which short steel cutting rods have been threaded.

As might be suspected, the moisture content required to initiate agglomeration varies with charge character. Charges containing higher proportions of fines accept more moisture and are less critical in control than more granular charges. Below a certain moisture content, agglomeration is ineffective; too much moisture results in oversize nodules not acceptable for *one-pass* sintering. As seen from the following typical pellet sizing data, an attempt is made to limit the maximum pellet size to ¼ in.

Mesh	Wt Pct
+4	9.1
+10	38.5
+20	31.7
+35	12.5
−35	8.2

From the pelletizing drum, the charge drops through a chute into a 7x30-ft Stearns-Roger rotary dryer, which operates at 11.3 rpm on a slope of ⅝ in. per ft. No lifters are used other than six ½-in. angle bars welded to the shell. The purpose of the dryer is to surface-harden the pellets. Very little actual drying is sought, only 1 to 1.5 pct moisture being removed.

The finished surface-set pellets leaving the dryer are conveyed via a partially hooded belt system to one of two sinter plant surge bins.

A marked increase in smelting capacity attended the start of the new preparation plant operations and the charge uniformity and control provided has enabled consistent maintenance of all subsequent operations at their highest capacity levels.

Reference

1 H. O. Hofman: *Metallurgy of Lead*, pp. 307-311. First edition, 1918.

Discussion of this paper (2 copies) sent to AIME before Dec. 1, 1956, will appear in AIME *Transactions*, Vols. 205 and 209, and in JOURNAL OF METALS, October 1957, and MINING ENGINEERING.

Sulfur Equilibria Between Gases and Slags Containing FeO

FeO slags with additions of CaO, SiO_2, and MgO were equilibrated with atmospheres of SO_2 containing additions of CO and O_2. At low partial pressures of oxygen, sulfur is present as sulfide, and at higher pressures, as sulfate. At constant oxygen and sulfur pressures, sulfur absorption as sulfide is nearly independent of the ratio CaO/FeO, but is decreased by addition of SiO_2 or MgO. The presence of CaO is necessary for absorption of sulfur as sulfate.

by George R. St. Pierre and John Chipman

METALLURGISTS have been studying the chemical behavior of sulfur in steelmaking for many years in order to have a better control of the sulfur content of finished steel. During the refining period in the open hearth, molten steel is separated from a gas phase by molten slag. Chemical reactions occur principally at the slag-metal interface and at the slag-gas interface. A need for physical-chemical investigations of reactions between sulfur-bearing gases and steelmaking slags was recognized some time ago.[1-4] From the early work, it can be qualitatively concluded that increased sulfur content and low partial pressure of oxygen in the gas phase favor the passage of sulfur from gas to slag. Using radioactive sulfur S^{35}, Koch and Fink[5] have demonstrated the rapid rate of exchange of sulfur between gas and slag in an open hearth furnace.

Gurry and Darken[6] and Darken and Shields (as reported by Derge and Marshall[7]) have equilibrated lime-iron oxide slags with SO_2—O_2 gas mixtures. The major conclusion from the reported results is that sulfur content increases with increasing lime content in lime-iron oxide slags equilibrated with a gas of high oxygen pressure (10^{-2}). The data were interpreted as indicating the presence of SO_4 and S_2O_7 ions.

Richardson and Fincham[8] have conducted the most extensive experimental study of sulfur equilibria between gas and slag. Their results confirmed many of the conclusions drawn from calculations of Richardson[9] and Withers.[10] Richardson and Fincham's data fitted very well into the sulfur scheme represented by the reactions

$$1/2\,S_2(g) + (O)\ \text{melt} = 1/2\,O_2(g) + (S)\ \text{melt} \quad [1]$$

$$1/2\,S_2(g) + 3/2\,O_2(g) + (O)\ \text{melt} = (SO_4)\ \text{melt}. \quad [2]$$

At oxygen pressures greater than 10^{-2} to 10^{-4}, they found that reaction Eq. 2 was predominant while reaction Eq. 1 was controlling at oxygen pressures less than 10^{-6} to 10^{-8}. The slag compositions and gas mixtures used in their investigations were different from those used in the present study. Wherever possible, comparison has been made between their results and these, and agreement is excellent.

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TP 4281C. Manuscript, Nov. 29, 1955. Chicago Meeting, February 1955.

It is evident that the distribution of sulfur between slag and gas depends upon the oxygen pressure of the gas. In FeO slags, a change in oxygen pressure produces a change in ferric oxide content, and a knowledge of this equilibrium is a prerequisite to studies of sulfur distribution. The data are found in the work of Darken and Gurry[11] on the FeO system and the more recent experiments of Gurry and Darken[6] and of Larson and Chipman[12] on FeO slags containing lime and silica. The effect of oxygen pressure on the ratio $Fe^{+++}/(Fe^{++} + Fe^{+++})$, the so-called *j-ratio*, reported by these investigators will be used in interpreting the results which follow.

Experimental Method

The purpose of the experimental program was to determine the equilibrium sulfur content in slags exposed to gases of known oxygen and sulfur pressures. The slag compositions selected for study were from the lime-silica-iron oxide system. Additions of magnesia were made to some of the slags.

Table I. Free Energy of Gas Reaction at Steelmaking Temperatures

Reaction	Equation
$2\,S\ (g) = S_2\ (g)$	$\Delta F^\circ = -86{,}500 + 29.20T$
$2\,O\ (g) = O_2\ (g)$	$\Delta F^\circ = -121{,}800 + 31.85T$
$S\ (g) + O\ (g) = SO\ (g)$	$\Delta F^\circ = -122{,}500 + 29.26T$
$\frac{1}{2}\,S_2\ (g) + \frac{1}{2}\,O_2\ (g) = SO\ (g)$	$\Delta F^\circ = -18{,}300 - 1.26T$
$SO\ (g) + \frac{1}{2}\,O_2\ (g) = SO_2\ (g)$	$\Delta F^\circ = -67{,}900 + 18.50T$
$\frac{1}{2}\,S_2\ (g) + O_2\ (g) = SO_2\ (g)$	$\Delta F^\circ = -86{,}200 + 17.26T$
$CO\ (g) + \frac{1}{2}\,O_2\ (g) = CO_2\ (g)$	$\Delta F^\circ = -68{,}560 + 20.15T$
$CO\ (g) + \frac{1}{2}\,S_2\ (g) = COS\ (g)$	$\Delta F^\circ = -20{,}300 + 18.07T$
$SO_2\ (g) + \frac{1}{2}\,O_2\ (g) = SO_3\ (g)$	$\Delta F^\circ = -19{,}800 + 19.76T$
$H_2\ (g) + \frac{1}{2}\,S_2\ (g) = H_2S\ (g)$	$\Delta F^\circ = -21{,}680 + 11.81T$
$H_2\ (g) + S\ (\text{in Fe}) = H_2S\ (g)$	$\Delta F^\circ = +6{,}500 + 8.37T$
$\frac{1}{2}\,S_2\ (g) = S\ (\text{in Fe})$	$\Delta F^\circ = -28{,}180 + 3.44T$

Apparatus—The apparatus used by Larson and Chipman was modified slightly to accommodate the addition of SO_2 to the gas mixtures. As in their work, slag samples of 0.5 to 2.0 g were held at temperature (±1°C) in platinum crucibles under a steady stream of gas, 100 to 200 ml per min, for several hours and then rapidly lowered to the bottom of the furnace where they were quenched in mercury.

Preparation and Analysis of Gas Mixtures—Mixtures of SO_2-CO were prepared from Virginia Smelting Co. *Extra Dry* liquid SO_2 and Pure Co. CO_2. After removing traces of water vapor with anhydrone, the CO_2 was passed over graphite at 1200°C, at which temperature the conversion to

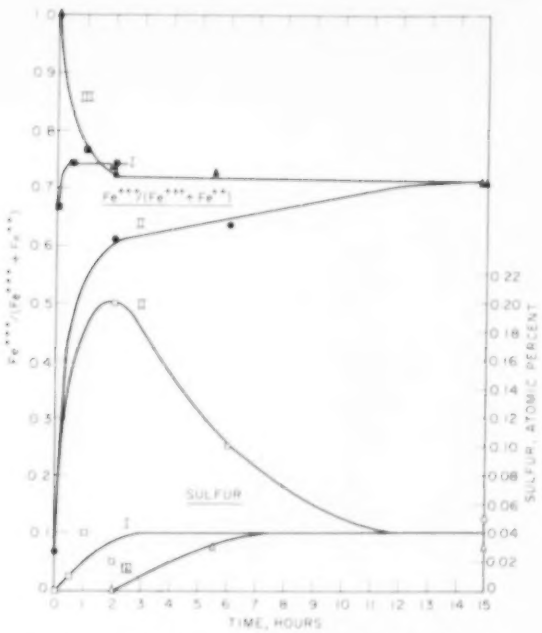

Fig. 1—Approach to equilibrium at 1550°C in a lime-iron oxide slag containing 12 atomic pct Ca. SO_2 atm.

CO is nearly complete. The remaining traces of CO_2 were removed with potassium hydroxide solution and ascarite. After removing traces of water vapor from the SO_2 with phosphorus pentoxide, it was mixed with the purified CO and the mixture was passed into the furnace. The ratio of SO_2 to CO could be varied by means of bleeder columns which, when set at a given level, held the gas flows constant. The composition of the gas mixture entering the furnace was determined gravimetrically. Samples of the gas mixture were flushed with N_2 through an analytical train consisting of an absorption bulb of ascarite, a CuO furnace at 400°C, and a second absorption bulb of ascarite in series. The ratio of the weight gain in the first absorption bulb to that in the second bulb was converted to give the volumetric SO_2/CO ratio of the gas mixture entering the furnace. CO_2 was not added as such to the mixture; it was formed in the furnace in amounts calculable from thermodynamic data to be given in a later section, Table I.

Table II. Loss of Sulfur in Slags Charged High in Both Ferric Iron and Sulfur at 1550°C. SO_2 Atm.

Charge Composition, Wt Pct				Time, Min	Analysis, Wt Pct		
Sample	CaO	Fe_2O_3	S		FeO	Fe_2O_3	S
K6	29.4	69.5	0.53	10	8.84	64.24	0.06
K7	29.4	69.5	0.53	22	10.01	63.44	0.07

Mixtures of purified SO_2 and oxygen were also prepared. Flow rates were controlled by bleeder columns, and room temperature composition was established by calibrated flowmeters with accuracy of ±0.5 pct. Using the free energy values given in Table I, the gas composition of heated SO_2:O_2 mixtures was calculated.

Chemical Analysis of Slags—The quenched samples were removed from the crucibles and crushed in a Plattner's diamond mortar to pass a 40 or 60 mesh screen with precautions to prevent oxidation. A portion of each of the slag samples was dissolved in air-free hydrochloric acid saturated with CO_2. Usually one portion of a sample was used to determine total iron, and a second portion was titrated for ferrous or ferric iron using $KMnO_4$ or $TiCl_3$. The presence of sulfur in the samples complicated the analysis because not all the sulfur was evolved as H_2S when the samples were dissolved. Some of the S^{--} produced on dissolving was oxidized to elemental sulfur by ferric iron. It was necessary, therefore, to determine the amount of H_2S evolved on dissolving each sample to correct the Fe^{+++}, Fe^{++} contents obtained from the titration analyses.

The sulfur contents were determined by two different methods: 1) combustion of the slag with CO_2 to remove the sulfur as SO_2 and titration of this SO_2 with KIO_3; and 2) gravimetric determination through the precipitation of sulfur as $BaSO_4$. Gravimetric analysis of sulfate content was made on some samples.

In addition, analyses for lime, magnesia, and silica were made on some samples. These analyses in all cases confirmed the calculation of the calcium, silicon, and oxygen contents from the analysis of ferric iron, ferrous iron, and sulfur and the known ratio of lime to silica.

Approach to Equilibrium—Generally a slag sample was charged with a ratio of ferric oxide to ferrous oxide, with a sulfur content added as ferrous sulfide close to that which would result from equilibration with the particular gas atmosphere. This was done to shorten the duration of the experiments. To be assured that equilibrium was being attained, the sulfur equilibrium and the FeO equilibrium were approached from both sides. A portion of the samples was charged slightly high in ferric oxide and low in sulfur while the remainder was charged slightly low in ferric iron and high in sulfur. It was impossible to charge very high in both ferric iron and sulfur because, immediately upon melting, the slag sample would evolve a sulfur gas which caused

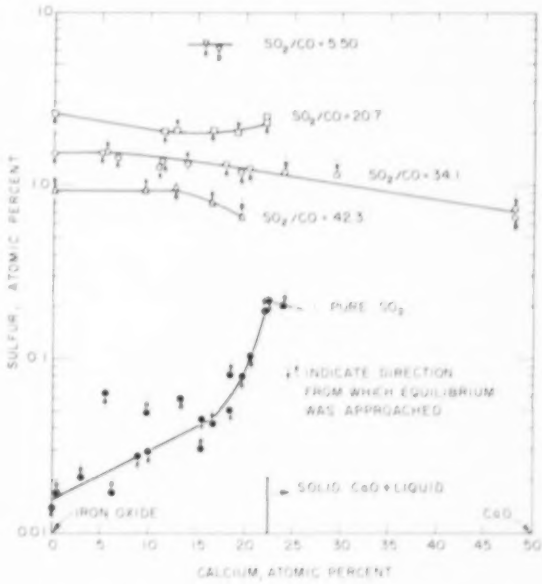

Fig. 2—Sulfur equilibria in lime-iron oxide slags at 1550°C. SO_2:CO atm.

Table III. Sulfur Equilibria in Lime-Iron Oxide Slags

	Sample	Sulfur Charge, Wt Pct	Time, Hr	Analysis, Wt Pct FeO	Fe_2O_3	CaO	Total S†	Atomic Pct Ca	S	j	log p_{O_2}
					Pure SO_2 at 1550°C						
	K8	6.6	0.5	18.80	59.95	21.25	0.01	12.0	0.01	0.741	
	K5	0.0	1.0	16.86	61.87	21.25	0.04	12.0	0.04	0.768	
	K1	0.0	2.0	18.58	59.85	20.17†	0.02	11.52	0.02	0.742	
	K4	0.4	2.0	18.90	59.14	21.96	0.00	12.38	0.00	0.740	
	K3	0.0	2.0	27.93	48.33	23.74	0.20	13.42	0.20	0.611	
	K16	0.0	6.0	26.4	52.2	21.4	0.10	12.33	0.10	0.637	
	K18	0.0	15.0	21.2	57.8	21.0	0.05	11.90	0.05	0.708	
	K2	0.0	2.0	19.94	58.74	21.32	0.00	12.06	0.00	0.725	
	K20	0.0	5.5	20.15	59.2	20.65	0.034	11.72	0.034	0.726	
	K19	0.0	15.0	21.2	57.6	21.2	0.027	11.97	0.027	0.710	
*	137	0.0	2.0	10.1	52.4	37.4	0.109	20.5	0.105	0.823	3.37¶
	138	0.0	2.0	5.35	53.1	41.3	0.250	22.4‡	0.237	0.902	2.40¶
	139	0.4	2.0	8.63	49.8	41.4	0.212	22.2‡	0.196	0.839	3.50¶
	150	1.5	4.0	7.91	47.6	44.3	0.220	23.9‡	0.206	0.845	3.40¶
	156	0.7	3.5	15.13	55.1	29.8	0.044	16.57	0.043	0.767	3.30
	158	0.7	6.3	10.71	55.9	33.4	0.084	18.38	0.081	0.825	2.90
*	1581	0.0	4.0	23.35	59.1	17.55	0.032	10.00	0.030	0.695	2.82
	1582	0.0	4.0	23.6	60.95	15.45	0.031	8.90	0.028	0.700	2.57
	1583	0.0	4.0	13.5	58.6	27.9	0.046	15.50	0.045	0.797	2.67
	1586	0.7	4.0	15.75	56.35	27.9	0.032	15.53	0.031	0.763	3.12
*	1587	0.0	18.5	43.15	56.6	0.25†	0.014	0.15	0.014	0.542	3.14
	1588	0.4	18.5	40.85	58.55	0.60†	0.016	0.36	0.017	0.564	2.94
	1589	0.0	18.5	7.55	56.15	36.3	0.084	19.80	0.080	0.870	2.54¶
*	1571	0.2	6.0	34.4	59.4	6.20	0.020	3.02	0.021	0.610	2.80
	1573	0.0	6.0	17.0	59.4	23.60	0.060	13.22	0.059	0.760	2.69
*	1574	0.2	13.5	30.0	59.45	10.55	0.017	6.11	0.017	0.641	2.74
	1576	0.0	13.5	12.25	54.65	33.1	0.053	18.3	0.051	0.801	3.21
*	1577	0.0	3.0	31.55	58.9	19.49	0.06	5.54	0.064	0.627	2.80
	1578	0.4	3.0	23.4	59.25	17.3	0.05	9.85	0.050	0.696	2.80
					$SO_2/CO = 42.3$ at 1550°C						
*	349	0.8	5.0	33.86	43.83	22.1	0.95	12.70	0.96	0.537	5.07
	350	1.0	5.0	26.64	44.18	29.0	0.81	16.42	0.80	0.598	5.12
	351	0.8	13.7	16.20	48.00	35.6	0.68	19.70	0.66	0.728	4.36
	418	1.4	6.5	62.5	34.6	0.00†	0.950	0.00	0.963	0.330	4.16
	419	1.3	6.5	41.65	41.6	16.30	0.952	9.57	0.943	0.473	5.20
	421	0.7	5.9	11.14	40.9	47.50	1.042	25.8‡	0.995	0.768	4.52
					$SO_2/CO = 34.1$ at 1600°C						
*	409	1.7	4.3	63.4	35.0	0.00†	0.776	0.00	0.822	0.333	
	410	1.0	4.3	36.4	42.2	31.0	0.926	17.48	0.915	0.590	
	411	1.6	4.3	26.8	42.2	30.6	0.979	17.28	0.966	0.587	
					$SO_2/CO = 34.1$ at 1500°C						
*	316	1.5	6.0	10.2	45.1	43.8	1.25	23.95‡	1.20	0.794	4.33
	314	0.50	6.0	33.3	44.8	23.0	1.04	13.47	1.08	0.549	5.11
	315	0.50	6.0	19.4	45.4	33.5	1.06	18.70	1.03	0.672	4.92
*	317	1.6	5.0	29.4	45.4	24.1	1.33	13.80	1.33	0.585	4.78
	318	1.6	5.0	44.8	44.6	9.3	1.49	5.52	1.55	0.477	4.45
	319	3.0	5.0	9.6	35.6	54.3	1.25	29.30‡	1.18	0.776	4.44
*	320	0.40	6.1	60.9	36.9	0.0†	1.07	0.0	1.14	0.362	4.88
	321	0.0	6.1	total Fe = 0.08		99.5	0.77	50.00‡	0.677	—	
	322	8.9	6.1	total Fe = 0.15		99.5	0.85	50.00‡	0.748	—	
*	335	1.2	6.8	37.86	42.42	19.1	1.35	11.13	1.38	0.501	5.18
	336	1.2	6.8	20.65	43.94	34.8	1.24	19.43	1.21	0.656	5.08
	337	1.2	6.8	49.61	41.39	8.35	1.48	5.04	1.56	0.428	4.91
*	341	1.2	11.0	37.15	43.04	19.3	1.27	11.00	1.28	0.511	5.31
	342	1.2	11.0	20.91	42.29	36.4	1.30	20.2	1.27	0.646	4.93
	343	1.2	11.0	50.56	38.19	10.7	1.34	6.62	1.46	0.404	5.42
	365	1.2	15.1	63.80	34.90	0.00†	1.441	0.00	1.55	0.330	5.20
	398	1.2	10.2	23.3	44.3	31.8	1.36	17.89	1.34	0.631	5.05

* Brackets indicate that samples were equilibrated simultaneously.
† Not calculated; all other CaO values were.
‡ Total sulfur by combustion or gravimetric analysis.
§ No sulfate was found by analysis.
‡‡ A solid phase was present.
¶ Not included in average log p_{O_2}.

** Calculation analysis reported as CaO.
†† For samples showing total sulfur; other figure is for sulfate analysis.
‡‡ Charged lime content.

foaming and spillage. In Table II data are presented to illustrate this point. Two samples of 1.5 g were raised individually to 1550°C, held for the time indicated in an atmosphere of SO_2, and quenched. Both samples had foamed over the crucible. The loss of sulfur from the sample held for 10 min can completely account for the increase in ferrous iron content through the reaction $S^{--} + 3\,O^{--} + 8\,Fe^{+++} \rightarrow 8\,Fe^{++} + \frac{1}{2}\,O_2 + SO_2$.

The time required to reach equilibrium is illustrated in Fig. 1 for a slag containing about 12 atomic pct Ca under pure SO_2 at atmospheric pressure. The study did not propose to determine the kinetics of sulfur transfer, but was intended to serve as a guide in selecting equilibration times. The plot shows the change with time of the ratio of ferric iron to total iron, hereafter referred to as j-ratio, and the sulfur content for three different charge compositions. In series II, the sulfur content rose far above equilibrium and then fell off. This is to be expected, because the initial iron balance of this slag dictated highly reducing conditions which favor increased sulfur content. Once the j-ratio neared equilibrium with the SO_2 atm, the sulfur content decreased, probably in accordance with the increase in j-ratio. It is impossible to give a complete kinetic treatment to the results, which are illustrative only. The primary test of attainment of equilibrium in this investigation was made by approach from both sides.

Results

Lime-Iron Oxide Slags—Table III summarizes the equilibrium data obtained. The effect of calcium on sulfur content of slags equilibrated with SO_2-CO mixtures is shown in Fig. 2. Analysis for sulfate in slags exposed to atmospheres containing CO always

Table III. Sulfur Equilibria in Lime-Iron Oxide Slags (Continued)

	Sample	Sulfur Charge, Wt Pct	Time, Hr	Analysis, Wt Pct FeO	Fe_2O_3	CaO	Total S‡	Atomic Pct Ca	S	j	$-\log p_{O_2}$
				$SO_2/CO = 34.1$ at 1550°C							
*	415	1.3	15.0	64.0	34.7	0.00	1.81	0.00	1.94	0.326	
	416	1.1	15.0	41.2	42.2	14.75†	1.76	9.29	1.81	0.480	
	417	1.1	15.0	16.1	43.85	39.3	1.74‖	21.80	1.69	0.710	
				$SO_2/CO = 34.1$ at 1450°C							
*	338	1.1	7.0	33.57	43.63	22.0	1.81	12.72	1.83	0.539	
	339	1.2	7.0	26.39	43.78	29.1	1.78	16.57	1.77	0.598	
	340	1.1	7.0	18.19	43.81	37.2	1.93‖	20.78	1.88	0.684	
*	406	2.1	13.0	64.2	33.5	0.0	2.09	0.0	2.24	0.320	
	407	2.0	13.0	26.3	42.9	29.9	1.81	17.02	1.80	0.595	
	408	2.1	13.0	15.9	43.3	39.8	2.00‖	22.1#	1.94	0.710	
				$SO_2/CO = 20.7$ at 1550°C							
*	302	0.0	5.6	38.3	41.4	19.3	2.02	11.3	2.05	0.492	5.30
	303	1.9	5.6	28.0	42.6	28.4	2.12	16.25	2.12	0.578	5.27
	304	0.0	5.6	16.3	43.0	39.4	2.62	22.0#	2.56	0.703	5.25
	304#	0.0	5.6	15.2	44.0	39.5	2.43	22.0#	2.36	0.722	5.10
*	424	2.0	23.0	64.38	31.54	0.0	2.40	0.0	2.60	0.308	5.43
	425	2.3	23.0			21.8	2.04	12.70	2.08		
	426	2.6	23.0			33.7	2.03‖	19.08	2.01		
				$SO_2/CO = 19.6$ at 1500°C							
*	311	0.0	4.4	34.3	43.4	20.4	1.46	12.34	1.47	0.532	
	312	1.9	4.4	26.3	45.0	27.9	1.61	15.89	1.60	0.606	
	313	0.0	4.4	18.1	45.2	35.9	1.53	20.00	1.49	0.691	
				$SO_2/CO = 20.5$ at 1450°C							
*	308	0.0	5.6	33.8	43.3	22.0	1.93	12.73	1.95	0.535	
	309	1.9	5.6	27.3	43.7	27.9	2.01	15.95	2.00	0.590	
	310	0.0	5.6	18.2	46.2	34.6	1.98	19.35	1.92	0.695	
				$SO_2/CO = 5.50$ at 1550°C							
*	300	0.0	4.0	30.4	39.8	26.7	6.51	15.7	6.67	0.541	5.52
	301	3.7	4.0	34.4	33.5	29.0	6.11	17.0	6.25	0.468	6.43
				$SO_2/O_2 = 3$ pct O_2 at 1550°C							
*	373	0.0	6.2	28.45	71.3	0.0†	0.032‖	0.0#	0.033	0.602	
	374	0.0	6.2	total Fe = 0.12		56.3**	16.6†† 49.9SO_4	46.8	24.35		
*	376	0.5	7.0	11.71	68.05	20.2	0.03‖	11.32	0.029	0.841	
	377	0.0	7.0	6.93	64.1	28.7	0.145†† 0.33SO_4	15.90	0.140	0.894	
	378	0.5	7.0	3.04	55.75	38.6	1.06†† 2.90SO_4	21.50	1.03	0.943	
				$SO_2/O_2 = 3$ pct O_2 at 1500°C							
*	382	0.0	6.0	28.3	70.8	0.0	0.023	0.0#	0.023	0.693	
	383	0.5	6.0	8.02	66.7	25.1	0.095†† 0.285SO_4	13.95	0.093	0.883	
	384	0.0	6.0	4.30	59.7	33.7	0.94†† 2.82SO_4	18.80	0.921	0.928	
				$SO_2/O_2 = 7$ pct O_2 at 1550°C							
*	392	1.0	10.3	5.42		30.01‡	0.100				
	393	0.0	10.3	22.97	71.90	4.23‡	0.019	2.43	0.019	0.738	

* Brackets indicate that samples were equilibrated simultaneously.
† Not calculated; all other CaO values were.
‡ Total sulfur by combustion or gravimetric analysis.
‖ No sulfate was found by analysis.
A solid phase was present.
* Not included in average log p_{O_2}.

** Calcium analysis reported as CaO.
†† For samples showing total sulfur; other figure is for sulfate analysis.
‡‡ Charged lime content.

proved negative. Analytical evidence and data for SO_2-O_2 atm support the conclusion that, in the slag samples close to lime saturation, sulfur was present as sulfate under pure SO_2. For the atmosphere $SO_2/CO = 34.1$, increases of calcium far in excess of that required to reach lime saturation were made. Beyond 22.5 pct Ca two phases were present: solid lime and liquid of constant composition, the proportion of solid to liquid increasing with increasing calcium content. Therefore, sulfur content should vary linearly between 22.5 and 50 pct Ca, with the intersection at 50 pct Ca corresponding to the solubility of sulfur in solid lime. Two samples of powdered lime were equilibrated with an atmosphere of $SO_2/CO = 34.1$. One sample was charged with 8.9 pct S added as CaS, and the other with no sulfur. The results indicated a solid solubility of CaS in CaO of 1.42 mol pct. Other aspects of the curves of Fig. 2 will be discussed more fully later.

For the atmosphere $SO_2/CO = 34.1$, the effect of additions of calcium on sulfur content at temperatures of 1450°, 1500°, 1550°, and 1600°C was determined, Fig. 3. The data for 1500° and 1600°C are fragmentary. Fig. 4 shows that temperature variations have no effect on the relation between calcium content and j-ratio. Increased temperature results in the development of greater oxygen pressures in this atmosphere, which would give rise to higher j-ratios if this were the only effect of temperature. Larson also found this behavior under CO_2-CO mixtures. It is certain that temperature can have an effect on the relationship between ferric iron activity and ferrous iron activity, and on the activity coefficients of each. It is impossible to isolate these several effects here.

Fig. 5 shows that 3 pct O_2 added to SO_2 results in increased sulfur contents, indicating that sulfur is present as sulfate. The samples containing about 0.1

Table IV. Equilibria in Lime-Silica-Iron Oxide Slags

Sample	Sulfur Charge, Wt Pct	Time, Hr	Analysis, Wt Pct				Atomic Pct			
			FeO	Fe_2O_3	CaO + SiO_2	Total S	Ca	Si	S	J
	$SO_2/CO = 42.3$ at 1550°C						$CaO/SiO_2 = 2.235$			
354	0.8	4.0	27.86	33.88	25.10CaO† 12.30SiO_2	0.79	14.59	6.65	0.73	0.522
	$SO_2/CO = 34.1$ at 1600°C						$CaO/SiO_2 = 2.235$			
414	0.5	4.0	6.80	12.90	80.20	0.26	25.3	11.33	0.21	0.631
	$SO_2/CO = 34.1$ at 1550°C						$CaO/SiO_2 = 2.235$			
325	0.0	5.2	29.0	33.35	36.3	0.87	12.75	5.71	0.79	0.506
[359	0.7	15.4	21.5	24.3	53.9	0.55	18.41	8.22	0.49	0.504
360	1.0	15.4	12.70	17.35	69.7	0.45	22.60	10.12	0.38	0.552
363	1.0	5.8	36.25	32.2	31.1	0.97	11.44	5.14	0.93	0.444
[400	1.5	14.6	49.8	36.7	8.18CaO† 12.11 Total	1.28	4.75	2.14	1.30	0.399
401	1.5	14.6	36.9	34.1	28.5	0.99	10.53	4.79	0.95	0.453
402	0.1	14.6	0.73	8.39	90.4CaO† 29.33SiO_2	0.33	27.15#	12.35	0.26	
	SO_2/O_2 – 7 pct O_2 at 1550°C						$CaO/SiO_2 = 2.235$			
[395	0.2	13.0	5.42	44.70	49.4	0.253‡ 1.029SO_4	16.78	7.53	0.222	0.882
396	0.0	13.0	2.17	21.95	74.3	0.925‡ 3.09SO_4	23.80	10.65	0.760	0.902
	$SO_2/CO = 42.3$ at 1550°C						$CaO/SiO_2 = 1.275$			
348	0.3	5.6	17.14	10.71	72.07	0.16	18.18	14.19	0.130	0.360
353	0.5	4.0	33.63	25.04	22.48CaO† 18.30SiO_2	0.45	11.58	8.99	0.409	0.400
423	0.2	5.9	9.24	3.97	86.8	0.05	20.95	16.35	0.039	0.279
	$SO_2/CO = 34.1$ at 1550°C						$CaO/SiO_2 = 1.275$			
324	0.0	5.2	34.35	25.7	39.5	0.53	11.23	8.80	0.48	0.402
[344	0.5	7.5	24.16	18.00	57.4	0.300	15.23	11.94	0.206	0.401
345	0.5	7.5	8.48	4.65	86.5	0.142	20.75	16.30	0.110	0.330
346	0.0	7.5	total Fe = 1.20		98.0	0.049	22.74	17.81	0.037	
[355	0.7	5.9	42.21	29.70	27.6	0.88	8.15	6.41	0.841	0.388
356	0.3	5.9	16.21	10.01	73.7	0.125	18.44	14.47	0.101	0.358
[357	0.5	67.0	51.1	36.0	12.6	1.35	3.96	3.10	1.38	0.388
358	0.6	67.0	32.1	22.7	44.8	0.58	12.43	9.75	0.518	0.389
	SO_2/O_2 – 3 pct O_2 at 1550°C						$CaO/SiO_2 = 1.275$			
[379	0.0	14.5	10.30	38.6	51.0	0.095	13.55	10.60	0.082	0.772
380	0.4	14.5	8.06	33.4	59.5	0.087	15.37	12.04	0.073	0.783
381	0.0	14.5	0.0	0.0	54.9CaO† 44.0SiO_2	0.295‡ 1.23SO_4	23.50	17.60	0.222	
	SO_2/O_2 – 7 pct O_2 at 1550°C						$CaO/SiO_2 = 1.275$			
[388	0.0	26.5	8.84	41.5	26.83CaO† 21.90SiO_2	0.053	13.27	10.10	0.048	0.809 0.812
389	0.4	26.5	4.08	19.63		0.210	18.73	14.67	0.167	
390	0.0	26.5	0.0	0.0	76.1	0.480	22.85	17.95	0.360	
	$SO_2/CO = 34.1$ at 1550°C						$CaO/SiO_2 = 0.524$			
323	0.0	5.2	40.4	16.0	43.2	0.26	7.10	13.56	0.225	0.263
366	0.0	15.1	total Fe = 0.16		99.5	0.049	12.95	24.72	0.034	
[367	0.4	4.3	30.0	6.77	62.7	0.042	9.47	18.15	0.034	0.169
368	0.4	4.3	13.5	3.35	82.7	0.030	11.52	22.01	0.022	0.182
[369	0.3	6.0	56.1	30.7	12.6	1.05	2.39	4.59	1.06	0.330
370	1.0	6.0	49.8	23.3	27.8	0.55	4.98	9.48	0.52	0.296
	SO_2/O_2 – 3 pct O_2 at 1550°C						$CaO/SiO_2 = 0.524$			
[385	0.0	23.0	15.10	23.43	61.5	0.017	9.15	17.50	0.014	0.583
386	0.4	23.0	11.43	16.35	72.2	0.026	10.33	19.70	0.020	0.563
387	0.0	23.0	total Fe = 1.69		97.8	0.039	12.73	24.4	0.027	

* Brackets indicate that samples were equilibrated simultaneously.
† Individual analyses; all others were calculated.
‡ Total sulfur by combustion or gravimetric analysis.
§ For samples showing total sulfur; other figure is for sulfate analysis.
# A solid phase was present.

pct S and higher were analyzed for sulfate, and the analyses showed that sulfate content could account for total sulfur content. With sulfur present as sulfate, it is to be expected that increased temperature would decrease sulfur content because of the greater instability of multiatom groupings at higher temperatures. In contrast to conditions where sulfide is predominant, calcium has a very marked effect on sulfur content. A sample of powdered lime was exposed to the atmosphere SO_2-O_2, 3 pct O_2, for 6 hr at 1550°C. The sample fused, and on quenching there was no evidence of a solid phase although the sample analyzed approximately 50 pct CaO and 50 pct $CaSO_4$. It is not known whether or not a longer exposure would have resulted in the lime being completely converted to $CaSO_4$. The data for equilibration with pure SO_2 is compared with the more oxidizing atmosphere. It is quite conclusive that, under pure SO_2 and SO_2-O_2 mixtures, sulfur is present as sulfate in slags with calcium contents near lime saturation.

Lime-Silica-Iron Oxide Slags—To investigate the effect of lime and silica jointly three master slag mixtures were used. These were the slags used by Larson and Chipman and had molar lime-to-silica ratios of 0.524, 1.275, and 2.235. Additions of these mixtures were made to cover the entire range from pure iron oxide to pure lime-silica mixture. The data obtained are summarized in Table IV.

Fig. 6 shows sulfur equilibria in these slags at 1550°C for an atmosphere of $SO_2/CO = 34.1$. Sulfur content, atomic pct, is plotted against the slag com-

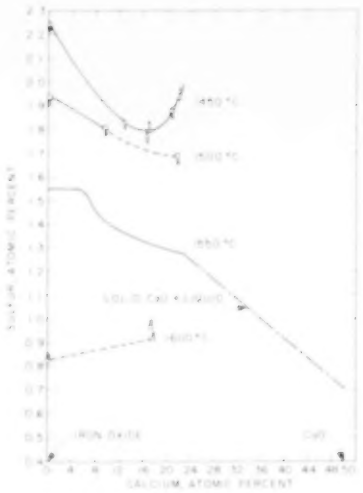

Fig. 3—Sulfur equilibria in lime-iron oxide slags. $SO_2/CO = 34.1$ atm.

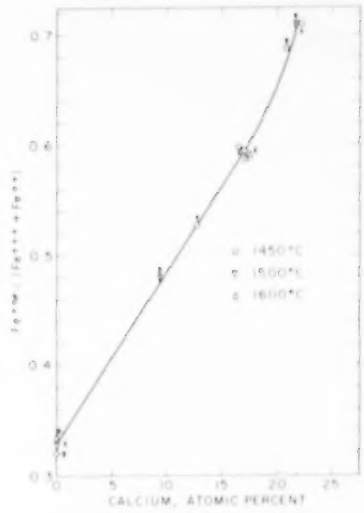

Fig. 4—Iron equilibria in lime-iron oxide slags. $SO_2/CO = 34.1$ atm.

position parameter (calcium + 3/2 Si), atomic pct. This parameter was used because it has the same value for a given iron content regardless of the calcium-to-silicon ratio. This can be shown by combining an electron balance with a total material balance to give the relation $N_{Ca} + 3/2\ N_{Si} + N_{Fe^{++}} + 5/4\ N_{Fe^{+++}} = 5$ O, where N is atomic pct. Thus, additions of the three lime-silica mixtures can be compared over the same numerical range.

Larson has discussed the phase relationships in the lime-silica-iron oxide slags investigated here. The two lower ratios are single-phase liquid throughout the entire range of composition. However, the 2.235 CaO/SiO_2 mixture results in the formation of a solid phase when present in large quantity. The evidence is that the solid phase formed is not pure dicalcium silicate. The solid definitely contains iron oxide with a j-ratio greater than that in the liquid with which it is in equilibrium. The exact point at which the solid begins to form cannot be located accurately. However, the slag sample containing the greatest addition of 2.235 CaO/SiO_2 shown on Fig. 6 was definitely two-phase. Fig. 7 shows iron equilibria in these slag mixtures at 1550°C for the same gas atmosphere.

Fig. 8 shows the variation of sulfur content under SO_2+O_2 at 1550°C with additions of the three lime-silica mixtures. Sulfate analyses again showed that the sulfur content of the lime-silica-iron oxide slags under the strongly oxidizing atmospheres is present predominantly as sulfate.

Slags Containing Magnesia—The solubility of magnesia in FeO at 1550°C is small, amounting to only 2.3 atomic pct Mg in slags which are in equilibrium with liquid iron. In slags of higher ferric oxide content such as those of samples 363, 364, and 403 shown in Fig. 6, the solubility is probably higher; even so, the two latter slags contained a solid phase. This solid is not pure MgO, but a solid solution of MgO, FeO, and Fe_2O_3 covering a wide range of composition. The j-ratio of the liquid slags is shown on Fig. 7. The points marked S on Figs. 6 and 7 are for samples containing magnesia and 1.275 CaO/SiO_2, as given in Table V. The molar ratio of (MgO + CaO) to SiO_2 was 2.20 and 2.14 for samples 404 and 405, respectively. The samples were single liquid phase. Two slags of almost exactly the same composition were equilibrated at 1600°C.

Discussion of Results

Thermodynamics of Sulfur Gases—At high temperatures SO_2 dissociates into SO and O_2. There is also dissociation, to a lesser extent, into S_2, sulfur, and oxygen and the possibility for formation of SO_3. In mixtures of SO_2 and CO, there is a substantial amount of CO_2 and the possibility of some COS. Thermodynamic properties of most of these species have been known for a long time, but those of SO and sulfur were very uncertain until the data of Table III had been determined. These data, in combination with the oxygen pressure data determined by Larson and Chipman[17] for the same slags, established the oxygen pressures in SO_2 and in the SO_2-CO mixtures used. This led to a clear-cut choice between several competing interpretations of the spectrographic data, thus fixing the dissociation constant of SO_2, the heat of formation of SO, and that of dissociation of S_2.

A full account of the calculations and a review of the data on sulfur gases has been presented by the

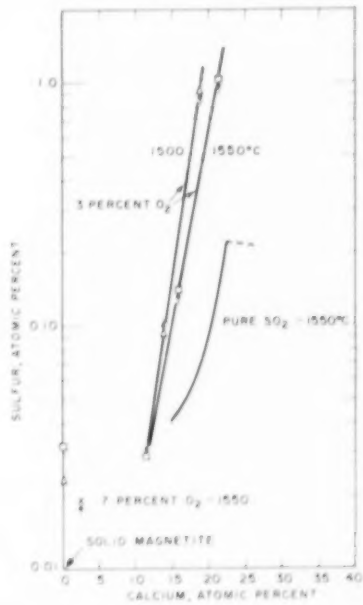

Fig. 5—Sulfur equilibria in lime-iron oxide slags. SO_2-O_2 atm.

Table V. Equilibria in Magnesia-Lime-Silica-Iron Oxide Slags

	Sample	Sulfur Charge, Wt Pct	Time, Hr	Analysis, Wt Pct FeO	Fe_2O_3	MgO	CaO + SiO_2	Total S‡	Atomic Pct Mg	Ca	Si	S	γ
						$SO_2/CO = 34.1$ at 1550°C							
*	383	1.0	4.1	57.5	36.3	5.7†	0.0	0.87	3.44	0.0	0.0	0.896	0.362
	384	1.4	4.1	52.8	35.7	10.65	0.0	0.36	6.42#	0.0	0.0	0.354	0.379
*	403	0.3	8.1	38.9	32.8	28.40	0.0	0.258	17.13#	0.0	0.0	0.229	0.432
	404	0.4	8.1	10.60	9.37	17.45	62.42	0.107	10.68	14.90	11.63	0.082	0.469
	405	0.1	8.1	10.47	9.20	16.75	63.53	0.097	10.25	15.15	11.90	0.075	0.469
						$SO_2/CO = 34.1$ at 1600°C							
*	412	0.4	4.0	11.11	10.51	16.56	61.75	0.120	10.48	15.28	11.97	0.093	0.486
	413	0.1	4.0	11.68	10.90	15.91	61.46	0.060	9.88	14.85	11.63	0.070	0.483
						SO_2-O_2—3 pct O_2 at 1550°C							
	378	0.0	8.2	20.45	73.2	6.63	0.0	0.025§	4.67#	0.0	0.0	0.025	0.764
						SO_2-O_2—7 pct O_2 at 1550°C							
	394	0.2	12.0	4.53	71.4§	24.00	0.0	0.118	15.22#	0.0	0.0	0.105	0.933

* Brackets indicate that samples were equilibrated simultaneously.
† Not analyzed; all other samples were.
‡ Total sulfur by combustion or gravimetric analysis.
§ No sulfate was found by analysis.
# A solid phase was present.
¶ Calculated by difference.

authors.[12] The pertinent data are summarized in the free energy equations of Table I, which represent the data at 1823°K and are of practical usefulness over a wide range of temperatures. The new data also required a slight correction[16] in the reaction of hydrogen with dissolved sulfur in liquid iron; the corrected equation and that for solution of S_2 in liquid iron are included. The data show that, in the SO_2-CO mixtures employed, the principal molecular species are SO_2, CO_2, CO, SO, S_2, and O_2. Partial pressures of the more important constituents at several temperatures are shown in Figs. 9 and 10.

Effect of Slag Composition on Sulfide Equilibrium—Reaction Eq. 1 can be written in terms of ionic constituents

$$O^{=} + 1/2\,S_2\,(g) = S^{=} + 1/2\,O_2\,(g). \qquad [3]$$

The equilibrium constant of reaction Eq. 3 is

$$K_s = \frac{a_{s^{=}}}{a_{o^{=}}} \times \left(\frac{p_{o_2}}{p_{s_2}}\right)^{1/2} \qquad [4]$$

which can be put in the form

$$(\%\ S) = K_s \times \frac{a_{o^{=}}}{\gamma_{s^{=}}} \left(\frac{p_{s_2}}{p_{o_2}}\right)^{1/2}. \qquad [5]$$

The quantity $(\%\ S)\ (p_{o_2})^{1/2}/(p_{s_2})^{1/2}$ has been given the name *sulfide capacity* by Richardson and Fincham.[8] It is related to the foregoing equilibrium expressions as follows

$$C_s = \frac{(\%\ S)\ (p_{o_2})^{1/2}}{(p_{s_2})^{1/2}} = K_s \frac{a_{o^{=}}}{\gamma_{s^{=}}}. \qquad [6]$$

The experimental data provide direct determinations of C_s and relative values of the ratio $a_{o^{=}}/\gamma_{s^{=}}$.

The experimental results indicate that additions of lime to iron oxide slags containing $S^{=}$ ion, up to lime saturation, produce a slight lowering in sulfur content. Applied to the data of Figs. 2 and 3, Eq. 6 indicates that there is no more than a 25 pct lowering in the ratio of oxide ion activity to activity coefficient of sulfide ion between pure iron oxide slags and slags saturated with lime. Thermodynamic data are available for the reaction

$$FeO\ (l) + CaS\ (s) = FeS\ (l) + CaO\ (s). \qquad [7]$$

At steelmaking temperatures,[15] $\Delta F^{\circ} = +430 + 0.16T$, which gives an equilibrium constant for reaction Eq. 7 of 0.82 at 1550°C. This indicates a nearly equal distribution of sulfur between iron and calcium and suggests that $\gamma_{s^{=}}$ may be essentially independent of calcium content in lime-iron oxide slags.

Bardenheur and Geller[10] concluded from slag-metal investigations that CaO was a better desulfurizer than FeO. They found that the distribution ratio of sulfur between slag and liquid iron increased when lime was substituted for iron oxide, and this observation has been confirmed many times. Conditions of constant gas composition are very different from those in slag-metal equilibrium where the oxygen pressure decreases markedly as CaO is substituted for FeO; and it will be shown that, for conditions of equal oxygen pressure, the two oxides are approximately equal in desulfurizing power.

Richardson and Fincham found from their studies on silicate melts that, for a given oxygen pressure, CaO-SiO_2 slags have a lower sulfur capacity than FeO-SiO_2 slags. They attributed this to the greater metal oxide activity in the ferrous silicate slags. It is only for the rather acid slags containing more than 33 mol pct SiO_2 that this statement is valid.

The effect of silica additions on sulfide content is shown in Fig. 6. The replacement of silicon for calcium at constant iron content results in a decrease in the ratio $a_{o^{=}}/\gamma_{s^{=}}$. The high strength of the Si-O bond produces low oxide ion activity when silicon contents are appreciable. Fig. 11 shows the direct relation between sulfur content and silicon content at constant oxygen pressure in CaO-SiO_2-FeO-Fe_2O_3 slags. The data for the three CaO:SiO_2 ratios are best fitted by a single curve, and hence in this composi-

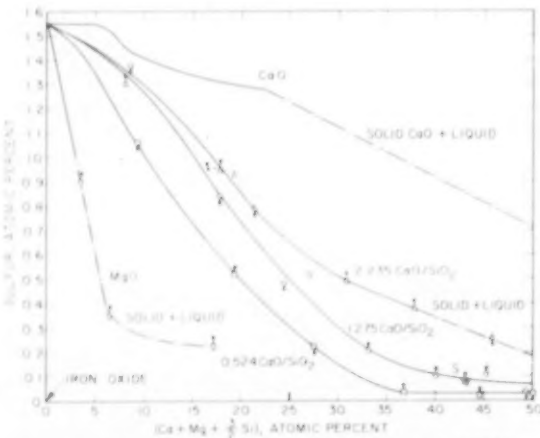

Fig. 6—Sulfur equilibria in iron oxide slags at 1550°C. $SO_2/CO = 34.1$ atm.

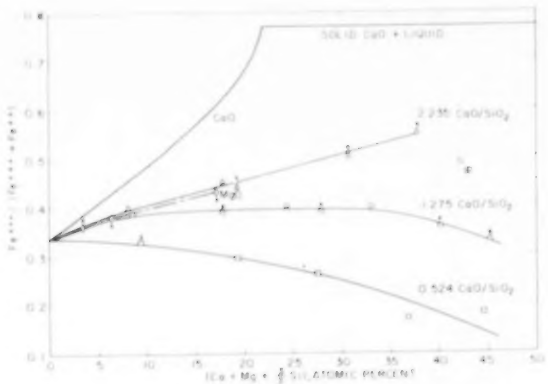

Fig. 7—Iron equilibria in iron oxide slags at 1550°C. $SO_2/CO = 34.1$ atm.

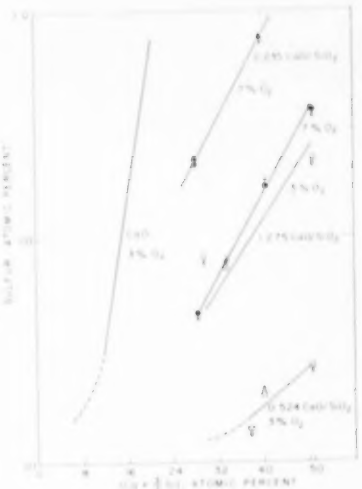

Fig. 8—Sulfur equilibria in lime-silica-iron oxide slags at 1550°C. SO_2-O_2 atm.

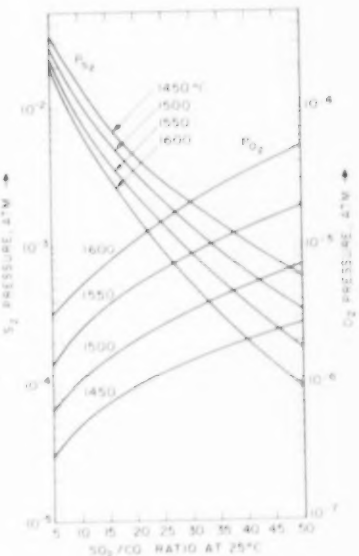

Fig. 9—Sulfur and oxygen pressures resulting from heating SO_2-CO mixtures to 1450°, 1500°, 1550°, and 1600°C.

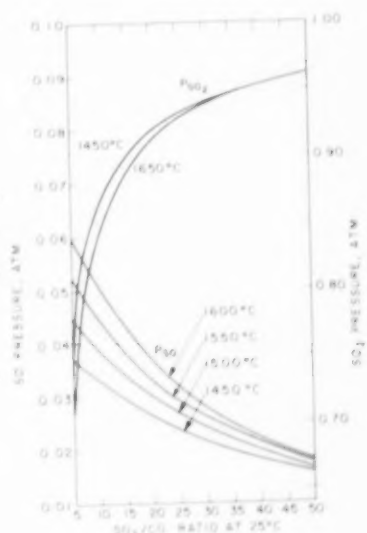

Fig. 10—SO_2 and SO pressures resulting from heating SO_2-CO mixtures to 1450°, 1500°, 1550°, and 1600°C.

tion range and at constant oxygen pressure, FeO and CaO are equal in their ability to hold sulfur. The interaction of sulfide and silicate to any appreciable extent is unlikely since Si-S bonds are far weaker than Si-O bonds.

The actual sulfur capacity of these slags is shown in Fig. 12, where log C_s is plotted against molar percentage of SiO_2. It must be noted that the data cover a wide range of iron oxide content and that within this range of composition C_s is a function of the silica concentration. The shape of the curve is similar to those of Richardson and Fincham, and the values of C_s are not greatly different from their data for high FeO slags in equilibrium with liquid iron.

If it is assumed that $\gamma_{s^=}$ is not varied appreciably over the range of sulfur contents shown in Fig. 11, then oxide ion activity is directly proportional to sulfur content, and Fig. 11 shows the relative change in $a_{o^=}$ produced by variation of silicon content. Up to 10 pct Si the data of Fig. 11 determine a straight line, which means that $a_{o^=}$ is a linear function of silicon content in this range. It is significant that the linear portion of the curve extrapolates to zero sulfur at an atomic fraction of silicon of about 13. In any mixed orthosilicate of calcium and ferrous ion, the atomic fraction of silicon is 14.3. The difference is due in part to the presence of ferric oxide. Allowing for the additional oxygen present in Fe_2O_3, the ratio $(CaO + FeO)/SiO_2$ becomes 2 at about 12 atomic pct Si. Similarly, the metasilicate composition, $(CaO + FeO)/SiO_2 = 1$, is reached at about 19 atomic pct Si. Here the sulfur content of the slag has reached a very low figure, corresponding to a low value of $a_{o^=}$.

From Fig. 6 it is seen that additions of MgO to iron oxide greatly lower sulfide-sulfur content both in the single liquid phase region and in the two-phase, solid and liquid, region. Fig. 7 shows that MgO has about one half the effect of CaO on the j-ratio, which is in agreement with the conclusions of Larson. Its effect on this ratio is about intermediate between that for additions of 1.275 CaO/SiO_2 and 2.235 CaO/SiO_2. Its effect on sulfur absorption is much greater than this. Accordingly, it must be concluded that addition of MgO to iron oxide slags greatly increases $\gamma_{s^=}$. This is supported by consideration of the reaction

$$FeO\ (l) + MgS\ (s) = FeS\ (l) + MgO\ (s). \quad [8]$$

At steelmaking temperatures,[10] $\Delta F^\circ = -21{,}270 + 0.26T$,

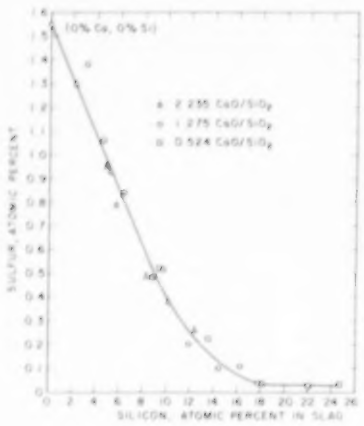

Fig. 11—Direct relation between silicon and sulfur content in CaO-SiO_2-FeO-Fe_2O_3 slags at 1550°C. SO_2/CO = 34.1 atm.

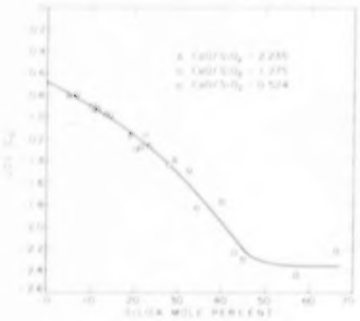

Fig. 12—Sulfur capacity C_s = (wt % S) $(p_{O_2}/p_{S_2})^{1/2}$ in lime-silica-iron oxide slags.

which gives an equilibrium constant of 2.6×10^7 at 1550°C. This indicates that the degree of association in molten slags between magnesium and sulfur is probably much less than that between ferrous iron and sulfur. However, this would only account for a lowering of sulfur content caused by dilution of ferrous iron with magnesium, which would be slight. The data thus indicate that magnesium must have an effect on the ability of Fe-S bonds to form. In Fig. 6, the two data points marked *S* represent slags of the series $CaO/SiO_2 = 1.275$ to which 17 pct MgO has been added (samples 404 and 405, Table V). The sulfur content of these samples was the same as would have been found if an equivalent quantity of the 1.275 CaO/SiO_2 slag had been added instead of MgO. The corresponding *j*-ratios shown in Fig. 7 are indicative of a more basic slag. It appears, therefore, that MgO contributes to the oxide ion concentration, but not to the desulfurizing power of the slag. Thus again magnesium increases $\gamma_{O^=}$, but the effect is smaller than in the case of the iron oxide slags. A possible explanation for this lies in the fact that viscosity and surface energy measurements[17] indicate that magnesium can take on a coordination number of four in silicate melts. The location of magnesium in this manner would prohibit its having an effect on the ability of Ca-S or Fe-S bonds to form. It seems reasonable that the lessened effect of MgO on $\gamma_{O^=}$ in the lime-silica-iron oxide slag might have been caused by a portion of the magnesium taking a coordination number of four.

In general, the results of Harders, Grewe, and Oelsen[10] support the observed behavior of MgO, showing that magnesium silicate slags were unable to desulfurize molten iron, whereas the corresponding calcium silicate effected an appreciable sulfur removal. Richardson and Fincham found the sulfur capacity of MgO-SiO_2 melts to be far less than that of CaO-SiO_2 melts.

Sulfate Equilibrium—Reaction Eq. 2 can be written in the form

$$O^= + 1/2\,S_2\,(g) + 3/2\,O_2\,(g) = SO_4^= \qquad [9]$$

and the corresponding sulfate capacity according to Richardson and Fincham is

$$C_{SO_4} = \frac{(\%\ S)}{(p_{S_2})^{1/2}\,(p_{O_2})^{3/2}} = K_9 \frac{a_{O^=}}{\gamma_{SO_4^=}} \qquad [10]$$

measured under conditions where the sulfur is present only as sulfate.

The effect of calcium content on sulfate equilibrium is entirely different from its effect on sulfide equilibrium, as seen by Fig. 5. A thirtyfold decrease in the activity coefficient of $SO_4^=$, reaction Eq. 4, is realized by increasing calcium content from 12 to 22 pct. This indicates that the degree of association between Fe^{++} or Fe^{+++} and $SO_4^=$ is far less than that between Ca^{++} and $SO_4^=$. The data also show that, in iron oxide slags containing less than about 10 pct Ca, sulfate does not form.

The effect of silicon content on sulfate equilibria is shown by the relative positions of the several curves of Fig. 8, which indicate that, for a constant iron content, the substitution of silicon for calcium lowers the sulfate content. The substitution of silicon for iron results in an increase in the fraction of positive charge held by calcium and, therefore, increases the availability of calcium for calcium-sulfate bonds. Apparently the net result is that the substitution of silicon for iron decreases $\gamma_{SO_4^=}$ in exactly the same proportion as it decreases $a_{O^=}$. It has already been shown that calcium greatly decreases $\gamma_{SO_4^=}$, and the lime-silica results indicate that the presence of silica does not interfere with the relation. This means that the bonding of calcium ions to silicate ions is not as strong as to sulfate ions.

Effect of Atmosphere on Sulfur Equilibria—The effects of variations in sulfur and oxygen pressures are shown by Eqs. 3 and 9. It is convenient to express these in terms of SO_2 and O_2 pressure through combination with the dissociation reaction of SO_2 into S_2 and O_2, Table I.

$$O^= + SO_2 = S^= + 3/2\,O_2 \qquad [11]$$

$$O^= + SO_2 + 1/2\,O_2 = SO_4^= \qquad [12]$$

In the present investigation, SO_2 pressure varied from 0.72 to 1.00 while O_2 pressure was varied from 1.6×10^{-4} to 7×10^{-4}. The equilibrium constants of reaction Eqs. 11 and 12 can be rearranged to yield the expressions

$$\frac{(S^=)}{p_{SO_2}} = K_{11} \frac{a_{O^=}}{\gamma_{S^=}}\,(p_{O_2})^{3/2} \qquad [13]$$

$$\frac{(SO_4^=)}{p_{SO_2}} = K_{12} \frac{a_{O^=}}{\gamma_{SO_4^=}}\,(p_{O_2})^{1/2}. \qquad [14]$$

Sulfide and sulfate contents are in terms of atomic pct S. These equations show that a plot of the logarithm of $\%\ S/p_{SO_2}$ against the logarithm of oxygen pressure for a constant calcium and silicon content has a slope of −1.5 when sulfur is present as sulfide and a slope of +0.5 when present as sulfate, provided that the effect of oxygen pressure on $a_{O^=}$, $\gamma_{S^=}$, and $\gamma_{SO_4^=}$ is not great. Fig. 13 shows that

the experimental data obey the requirements reasonably well. Three slags covering an extremely wide range of composition are shown.

The data can be extended to low oxygen pressures to include slag-metal data[19,20] by means of the free energy data given in *Basic Open Hearth Steelmaking*.[10] These are shown by a representative average line for oxygen pressures below 10^{-8} atm. It is seen that a line with slope of -1.5 drawn through the experimental determinations of this investigation passes through the slag-metal equilibrium data.

If data were available for oxygen pressures close to the intersections of the sulfate and sulfide lines on Fig. 13, the values of $(\%\ S)/p_{so_2}$ would probably be greater than those given by the intersection. At these oxygen pressures, both sulfide and sulfate would be present in moderate amount, and the curves for a given calcium and silicon content should join with a smooth minimum. There is a strong possibility that pyrosulfate, $S_2O_7^{=}$, is formed in the region of the minimum as indicated by Darken.[6,7]

Effect of Temperature on Sulfur Equilibria—It has already been shown in Fig. 5 that in the sulfate range an increase in temperature decreases the sulfur content of the slag. A similar relation for sulfide-sulfur is shown in Fig. 14. It should be noted, however, that the conditions of the experiment are for a constant ratio of SO_2/CO, and not for constant pressures of O_2 and S_2. The sulfur capacity of the slag as measured by the ratio $(\%\ S)(p_{so_2}/p_{s_2})^{1/2}$ increases strongly with increasing temperature. Hence, in these slags, if partial pressures of O_2 and S_2 were maintained constant, the sulfur content of the slag would increase with rising temperature.

Conclusions

Sulfur equilibria between gases and slags are adequately described by the reactions

$$O^{=}\ (slag) + 1/2\ S_2\ (g) = S^{=}\ (slag) + 1/2\ O_2\ (g)$$

$$O^{=}\ (slag) + 1/2\ S_2\ (g) + 3/2\ O_2\ (g) = SO_4^{=}\ (slag).$$

The first is controlling at oxygen pressures less than about 3×10^{-8} atm, while the second governs sulfur content at oxygen pressures greater than about 3×10^{-4} atm. The equilibria have been studied in gas mixtures of SO_2 with CO or O_2 in which the partial pressures of S_2 and O_2 are known.

In lime-iron oxide slags at constant atmospheric conditions, the substitution of CaO for iron oxide slightly decreases sulfide content and greatly increases sulfate content.

Addition of silica to lime-iron oxide slags lowers the sulfur content under a given atmosphere because of the lowering in oxide ion activity. In the ternary basic slags CaO and FeO have about the same effect on sulfur absorption at constant oxygen pressure.

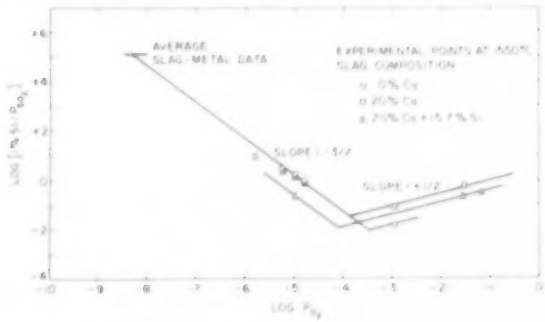

Fig. 13—Effect of oxygen pressure on sulfur equilibria in iron oxide slags at 1550°C.

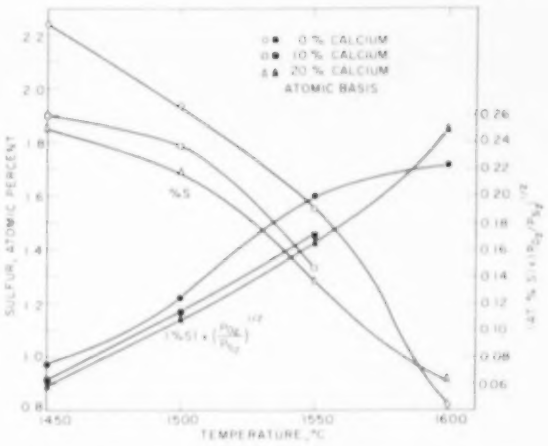

Fig. 14—Effect of temperature on sulfur equilibria in iron oxide slags. $SO_2/CO = 34.1$ atm.

Magnesia additions to slags increase the activity coefficient of sulfide ion, which favors low concentration of sulfur in slag.

For a constant input gas composition, the sulfur content of the slag decreases with increasing temperature. In view of dissociation in the gas, it is found that in the sulfide range at constant oxygen and sulfur pressures, the sulfur content of the slag increases with increasing temperature; in the sulfate range, it decreases.

Acknowledgments

D. L. Guernsey and his associates are thanked for the analytical work performed in this investigation. The authors are also grateful to the Republic Steel Corp., the Union Carbide and Carbon Corp., and the American Iron and Steel Institute for support of this research. This paper is based on a portion of a thesis by George R. St. Pierre submitted in partial fulfillment of the requirements for the degree of Doctor of Science to the Massachusetts Institute of Technology.

References

[1] J. H. Nead: *AIME Trans.*, 1924, vol. 70, p. 176.
[2] J. H. Whitely: *Journal* West Scotland Iron and Steel Inst., 1923, vol. 31, p. 42.
[3] A. N. Diehl: *AISI Year Book*, 1926, p. 404.
[4] C. H. Herty, A. R. Belzea, E. B. Burkart, and C. C. Miller: *AIME Trans.*, 1925, vol. 71, p. 512.
[5] W. Koch and K. Fink: *Archiv für Eisenhuttenwesen*, 1951, vol. 22, p. 371.
[6] R. W. Gurry and L. S. Darken: *Journal* ACS, 1950, vol. 72, p. 3906.
[7] G. Derge and S. Marshall: JOURNAL OF METALS, 1951, vol. 3, p. 511.
[8] F. D. Richardson and C. J. B. Fincham: *Journal* Iron and Steel Inst., London, 1954, vol. 178, p. 4.
[9] F. D. Richardson: *Discussions* Faraday Soc., 1948, No. 4, p. 340.
[10] F. D. Richardson and G. Withers: *Journal* Iron and Steel Inst., London, 1950, vol. 165, p. 66.
[11] L. S. Darken and R. W. Gurry: *Journal* ACS, 1945, vol. 67, p. 798; 1946, vol. 68, p. 798.
[12] H. R. Larson and J. Chipman: *AIME Trans.*, 1953, vol. 197, p. 1089; JOURNAL OF METALS, September 1953.
[13] G. St. Pierre and J. Chipman: *Journal* ACS, 1954, vol. 76, p. 4787.
[14] J. A. Cordier and J. Chipman: *AIME Trans.*, 1955, vol. 203, p. 905; JOURNAL OF METALS, August 1955.
[15] *Basic Open Hearth Steelmaking*, AIME, New York, 1951.
[16] P. Bardenheur and W. Geller: *Mitt. Kaiser-Wilhelm Inst. für Eisenforschung*, 1934, vol. 16, p. 77.
[17] T. B. King: *The Physical Chemistry of Melts*, Inst. of Mining and Metallurgy, London, 1953.
[18] F. Harders, H. Grewe, and W. Oelsen: *Stahl und Eisen*, 1951, vol. 71, p. 973.
[19] K. L. Fetters and J. Chipman: *AIME Trans.*, 1940, vol. 140, p. 170.
[20] N. J. Grant and J. Chipman: *AIME Trans.*, 1946, vol. 167, p. 134.

Discussion of this paper sent (2 copies) to AIME by Dec. 1, 1956 will appear in AIME *Transactions* Vol. 209, 1957, and in JOURNAL OF METALS, October 1957.

Technical Note

Matrix Phase in Lower Bainite and Tempered Martensite

by F. E. Werner, B. L. Averbach, and Morris Cohen

THAT bainite formed near the M_s temperature bears a striking resemblance to martensite tempered at the same temperature has been shown by the electron microscope.[1] By means of electron diffraction,[2] it has been established that ϵ carbide and cementite are present in bainite formed at 500°F (260°C); these carbides are also found in martensite tempered at 500°F (260°C).[3, 4]

The investigation reported here is concerned with an X-ray study of the matrix phases in lower bainite and tempered martensite. These phases have turned out to be dissimilar in structure; the matrix of bainite is body-centered-cubic while that of tempered martensite is body-centered-tetragonal.

A vacuum-melted Fe-C alloy containing 1.43 pct C was studied. Specimens of ⅛ in. diam were sealed in evacuated silica tubing and austenitized at 2300°F (1260°C) for 24 hr. One specimen was quenched into a salt bath at 410°±7°F (210°±4°C), held for 16 hr, and cooled to room temperature. The structure consisted of about 90 to 95 pct bainite, the remainder being martensite and retained austenite. A second specimen was quenched from the austenitizing temperature into iced brine and then into liquid nitrogen. It consisted of about 90 pct martensite and 10 pct retained austenite. The latter specimen was tempered for 10 hr at 410°±2°F (210°±1°C).

The specimens were then fractured along prior austenite grain boundaries (grain size about 2 mm diam) by light tapping with a hammer. Single austenite grains, mostly transformed, were etched to about 0.5 mm diam and mounted in a Unicam single crystal goniometer, which allowed both rotation and oscillation of the sample. Lattice parameters were measured by the technique of Kurdjumov and Lyssak.[5] This method takes advantage of the fact that martensite and lower bainite are related to austenite by the Kurdjumov-Sachs orientation relationships.[6] Thus, the (002) and the (200) (020) reflections can be recorded separately, permitting the c and a parameters to be determined without interference from overlapping reflections.

According to these findings, the matrix phase in bainite is body-centered-cubic and, within experimental error, has the same lattice parameter as ferrite (2.866A). On the other hand, martensite, tempered as above, retains some tetragonality, with a c/a ratio of 1.005±0.002.

Most workers in the past have assumed that bainite is generated from austenite as a supersaturated phase, but the nature of this product has not been established. The question arises as to whether bainite initially has a tetragonal structure and then tempers to cubic, or if it forms directly as a cubic structure. If it forms with a tetragonal lattice, it might well be expected to temper to the cubic phase at about the same rate as tetragonal martensite.

The martensitic specimen used here was given approximately the same tempering exposure, 10 hr at 410°F, as suffered by the greater part of the bainite during the isothermal transformation. About 50 pct bainite was formed in 6 hr at 410°F. On tempering at this temperature, martensite reduces its tetragonality within a few minutes to a value corresponding to 0.30 pct C.[6] Further decomposition proceeds slowly, and after 10 hr the c/a ratio is still appreciable, i.e., 1.005. Thus, even if the bainite were to form as a tetragonal phase with a tetragonality corresponding to only 0.30 pct C, which might be assumed to coexist with ϵ carbide,[7] it would not be expected to become cubic in this time. It seems very likely, therefore, that bainite forms from austenite as a body-centered-cubic phase and does not pass through a tetragonal transition. The carbon content of the cubic phase has not been determined, but it could easily be as high as 0.1 pct, within the experimental uncertainty of the lattice-parameter measurements.

It has been postulated[8] that retained austenite decomposes on tempering into the same product as martensite tempered at the same temperature. There is now considerable doubt on this point. The isothermal transformation product of both primary and retained austenite at the temperature in question here is bainite,[9] and the present findings show that bainite and tempered martensite do not have the same matrix.

Acknowledgments

The authors would like to acknowledge the financial support of the Instrumentation Laboratory, Massachusetts Institute of Technology, and the United States Air Force.

References

1 Electron Microstructure of Steel. *Proceedings* ASTM, 1950, vol. 50, p. 444.
2 A. E. Austin and C. M. Schwartz: Electron-Diffraction Study of Iron Carbides in Bainite and Tempered Martensite. *Proceedings* ASTM, 1952, vol. 52, p. 592.
3 K. H. Jack: Structural Transformations in the Tempering of High-Carbon Martensitic Steels. *Journal* Iron and Steel Inst., 1951, vol. 169, p. 26.
4 G. Kurdjumov and L. Lyssak: The Application of Single Crystals to the Study of Tempered Martensite. *Journal* Iron and Steel Inst., 1947, vol. 156, p. 29.
5 B. S. Lement, B. L. Averbach, and M. Cohen: Microstructural Changes on Tempering Iron-Carbon Alloys. *ASM Trans.*, 1954, vol. 46, p. 851.
6 G. V. Smith and R. F. Mehl: Lattice Relationships in Decomposition of Austenite to Pearlite, Bainite, and Martensite. *AIME Trans.*, 1942, vol. 150, p. 211.
7 F. E. Werner, B. L. Averbach, and M. Cohen: The Tempering of Iron-Carbon Martensite Crystals. *ASM Trans.*, 1957, vol. 49.
8 C. S. Roberts, B. L. Averbach, and M. Cohen: The Mechanism and Kinetics of the First Stage of Tempering. *ASM Trans.*, 1953, vol. 45, p. 576.
9 J. Crangle and W. Jucksmith: Magnetic Analysis of Iron-Carbon Alloys. *Journal* Iron and Steel Inst., 1951, vol. 168, p. 141.
10 R. W. Balluffi, M. Cohen, and B. L. Averbach: The Tempering of Chromium Steels. *ASM Trans.*, 1951, vol. 43, p. 497.

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AIME NEWS

Annual Off-the-Record Meeting in Pittsburgh

The Pittsburgh Section AIME, in cooperation with the Engineers' Society of Western Pennsylvania, will hold its Eleventh Annual Off-the-Record Meeting on November 2, at the Penn Sheraton Hotel, Pittsburgh. Also participating are the Coal Division, Petroleum Subsection, Institute of Metals Group, National Open Hearth Committee and Minerals and Metals Economic Committee.

General chairmen of the meeting are W. D. Doty, U. S. Steel Corp., and W. O. Philbrook, Carnegie Institute of Technology, with D. H. Davis, Mathies Coal Co., assisting as vice chairman.

Of particular interest to readers of the JOURNAL OF METALS will be the sessions of the Institute of Metals Group, the National Open Hearth Steel Committee, the Minerals and Metals Economic Committee, and the Acid Open Hearth Session. Other sessions are scheduled by the Coal Division and the Petroleum Subsection.

PROGRAM

Institute of Metals Group
Morning Session 9:30 am

Chairman: R. H. Aborn, U. S. Steel Corp.

1. **The Effect of Impurities on the Preferred Casting Orientation of Face Centered Cubic Materials**
   W. A. Tiller, Westinghouse Electric Corp.
2. **A Filtering Method for the Study of Metallurgical Liquid-to-Solid Equilibria**
   L. A. Willey, ALCOA, New Kensington, Pa.
3. **A Calorimetric Investigation of Eutectoid Reactions**
   J. J. Cramer, Carnegie Institute of Technology.
4. **Abrupt Yielding of the Ductile-to-Brittle Transition in Body-Centered-Cubic Materials**
   E. T. Wessel, Westinghouse Electric Corp.

Luncheon 12:30 pm
Afternoon Session 2 pm

Chairman: H. T. Clark, Jones & Laughlin Steel Corp.

1. **Improvement of High-Temperature Alloys by Vacuum Melting**
   W. J. Pennington, Universal-Cyclops Steel Corp., Bridgeville, Pa.
2. **One Pct Boron Stainless Steels**
   J. A. Berger, University of Pittsburgh.
3. **Elevated Temperature Mechanical Properties of a Nickel-Free Austenitic Stainless Steel**
   R. R. Brady, U. S. Steel Corp., Monroeville, Pa.
4. **Effect of Silicon, Aluminum, Beryllium, and Phosphorus on the Third Stage of Tempering**
   A. G. Allten, Crucible Steel Corp. of America.

National Open Hearth Steel Committee
Morning Session 9:30 am

Co-Chairmen: E. J. Lichy, Jones & Laughlin Steel Corp., and G. L. Owens, Bethlehem Steel Co.

1. **Metallurgical Control in the Production of Leaded Steels**
   W. D. Smith, Jones & Laughlin Steel Corp., Aliquippa, Pa.; C. H. Weimer, Copperweld Steel Co., Warren, Ohio; and L. J. Trilli, Inland Steel Co., East Chicago, Ind.
2. **The Relation Between Manganese in the Charge and Sulfur Removal in the Open Hearth**
   C. R. Boisture and E. L. Scheuer, U. S. Steel Corp., Braddock, Pa.; and R. J. Conklin, Wheeling Steel Corp., Steubenville, Ohio.
3. **Mold Deoxidation of Rimmed and Mechanically Capped Steel**
   A. C. Coulson, Wheeling Steel Corp., Steubenville, Ohio; E. L. Bartolotta, U. S. Steel Corp., Morrisville, Pa.; E. W. Stotz, Bethlehem Steel Co., Johnstown, Pa.; and A. J. MacDonald, Weirton Steel Co., Weirton, W. Va.
4. **The Use of Vibrating Feeders for Ferro-Alloy Additions**
   J. W. McGill, U. S. Steel Corp., Munhall, Pa.; and T. G. Harkins, Crucible Steel Co., Midland, Pa.
5. **The Continuous Oxygen Analyzer as an Aid to Operation**
   F. S. Swaney, Jones & Laughlin Steel Corp., Pittsburgh.

Luncheon 12:30 pm
Afternoon Session 2 pm

Co-Chairmen: D. L. Olenchuk, Jones & Laughlin Steel Corp., and E. A. Vierow, Youngstown Sheet & Tube Co.

1. **Combustion Studies in a Scale Model Open Hearth**
   J. H. Richards, U. S. Steel Corp.
2. **Atomization of Fuel Oil**
   a. *Atomization with High Pressure Natural Gas*
      R. G. Renninger, U. S. Steel Corp.
   b. *Jet Atomization*
      Grover Nuzum, Wheeling Steel Corp., Steubenville, Ohio.

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(Continued from page 1485)

c. *Metallurgical Aspects of Driven Fuel Atomization in the Open Hearth*
J. H. Richards, U. S. Steel Corp.

3. **Recent Developments in the Use of Basic Refractories**
D. M. Schrader, Republic Steel Corp., Canton, Ohio; J. A. Certoni, U. S. Steel Corp., Munhall, Pa.; John Craig, Jones & Laughlin Steel Corp., Pittsburgh; and E. B. Snyder, Wheeling Steel Corp., Steubenville, Ohio.

4. **Rapid Heating of Open Hearth Checkers after Rebuild**
V. W. Jones, Armco Steel Corp., Middletown, Ohio.

National Open Hearth Steel Committee
Acid Open Hearth Session 9:30 am

Co-Chairmen: C. R. Funk, Alco Products Co., and G. E. Danner, Erie Forge & Steel Corp.

1. **The Effect of Phosphorus and Sulfur on Impact Strength**
F. W. Boulgar, Battelle Memorial Institute, Columbus, Oh..o.
Prepared Discussion by C. F. Christopher, Blaw Knox Co., E. Chicago, Ind.; and P. A. Archibald, Baldwin-Lima-Hamilton Co., Burnham, Pa.

2. **The Use of Basic End Walls**
J. G. Blythe, John A. Roebling's Sons Co., Trenton, N. J.

Minerals and Metals Economic Committee
Morning Session 9:30 am

Chairman: H. A. Franke, ALCOA

1. **Synthetic Nonmetallic Minerals**
H. R. Shell, Bureau of Mines, Norris, Tenn.

2. **Use of Nonmetallic Minerals by Industry**
R. D. Thomson, Bureau of Mines, Pittsburgh.

3. **New Processes in Steel Making**
D. F. McBride, U. S. Steel Corp., Pittsburgh.

4. **Description of the Columbia Falls, Montana, Aluminum Reduction Plant of Anaconda Aluminum Co.**
J. F. Smith, Anaconda Aluminum Co.

Luncheon 12:30 pm
Afternoon Session 2 pm

Chairman: C. F. McCabe, Carnegie Institute of Technology

1. **Problems in Abatement of Metallurgical Fume**
Richard Engdahl, Battelle Memorial Institute, Columbus, Ohio.

2. **Recent Developments in Extractive Metallurgy**
F. W. Coffer, Battelle Memorial Institute, Columbus, Ohio.

3. **Economic Consideration in Liquid Waste Disposal**
McCloyd Snauley, Battelle Memorial Institute, Columbus, Ohio.

4. **SO_2 Distribution in Flash and Fluid Roaster Gases**
R. G. Redelfs, St. Joseph Lead Co., Monaca, Pa.

Suppliers' Cocktail Party 5:45 pm
Fellowship Dinner 7 pm

Toastmaster: N. K. Flint
Presentation—F. L. Toy Award
Student Prize Paper Award
Dinner Speaker: Perry E. Gresham, president, Bethany College.

ESPS Chicago Office Reports on Employment Picture as Seen by Personnel Service

The Chicago office of the Engineering Societies Personnel Service Inc. has made a study recently of the registrations and job opportunities in their current or active files. This resulted in some figures of interest to the engineering and scientific professions.

The first joint effort of the Engineering Societies to establish an employment office was in 1918. The management was taken over in 1923 by the Founder Societies, AIME, ASChE, ASME, and AIEE, and the Boards of Direction inaugurated a new policy respecting the Employment Service. The Service was confined to members of the four National Societies and cooperating organizations until 1929, when it was felt that more effective service could be rendered by offering it to nonmembers at a higher charge. Offices were soon established throughout the country. The Chicago office was opened in 1925 and administered by representatives from the sections of the Founder Societies in Chicago, in cooperation with the Western Society of Engineers, which also gave financial support. Other branches were later established in San Francisco, Detroit, and Boston.

Since the first of the year, the Chicago office of the ESPS has averaged better than two and one half job opportunities for every man registered. This indicates that it is the ideal time for any person seeking new or better employment to register with the Chicago office.

Of the jobs studied, 44 pct were at salaries of $7000 a year and lower; 44 pct at salaries ranging from $7000-$10,000 a year; and 12 pct over $10,000 a year. The heaviest demand, 44 pct of the jobs, is in a range where only 21 pct of the applicants are available. Only 25 pct of the employers still expect the applicant to pay his own fee.

Taking the above figures into consideration, the Chicago office of ESPS requested the National Board of Directors to grant permission for conversion to the 100 pct Employer Pays Fees Plan. Approval was granted, and by the time this is published the conversion will be complete.

Powder Metallurgy Group Meeting

The Powder Metallurgy Group of the New York Section, AIME, met on Wednesday evening, September 12, at the Brass Rail Restaurant on Fifth Avenue in N. Y. A panel discussion was held on the subject of *Finishing and Secondary Operations on Metal Powder Parts*. The first speaker was Joseph Bonanno, chief engineer, Lionel Corp., who discussed plating, blackening, painting, and welding of parts produced by powder metallurgy techniques. He was followed by Bradford Horton, staff engineer, Pitney-Bowes Inc., who described impregnating, heat treating, and machining of powder metallurgy parts. R. P. Seelig, concluding speaker, described the chromizing operation. Mr. Seelig is executive vice president of the Chromalloy Corp.

Kempton H. Roll, Executive Secretary of the Metal Powder Assn., served as chairman of the meeting. This was the first meeting of the 1956-57 season for the Powder Metaliurgy Group of the N. Y. Section which meets four times each year.

St. Louis Cathedral is one of the landmarks AIME members can visit in New Orleans.

Engineering Foundation Grants Research Funds

The following cash grants have been approved by the AIME Committee on Research and the Engineering Foundation for research studies, in the year ending Sept. 30, 1957: J. L. Gregg, *Alloys of Iron Research*—$5,000; V. Paschkis, *Heat Flow in Quenching*—$2,000; Morris Cohen, *Diffusion in Steel*—$2,500; D. W. Fuerstenau, *Comminution*—$2,000; R. M. Burns, *Corrosion Research Council*—$3,000; M. Simnad, *Surface Diffusion of Metals*—$3,000; A. M. Gaudin, *Thickening and Thickeners*—$2,500; A. W. Huff, *Effect of Strain Waves in Blasting*—$1,500; William L. Donn, *Storm Surges*—$2,000.

Membership Award

In order to give greater recognition to members who have gone all-out by securing 50 membership applications, a special award has been designed.

The award will be a 14kt gold tie clasp utilizing the present design of the pin awards.

As of this time, two members are eligible for the award, Cloyd Henline and Robert Moscrip, III.

Mr. Carl Reistle, Jr., president of AIME, will present these awards at the all-AIME session in New Orleans on Tuesday, February 26.

It is fervently hoped that the gentlemen will be in attendance and that others shall join their ranks as the Annual Meeting approaches.

AIME 1957 ANNUAL MEETING

Plans for the 1957 AIME Annual Meeting are progressing nicely. Scheduled for February 24-28, at the Roosevelt and Jung Hotels in New Orleans, the meeting will feature technical sessions and symposiums as well as luncheons and a banquet. Metals Branch headquarters will be at the Jung Hotel. Members who plan to attend should make arrangements early. For details and registration blank see page 1112A, August JOURNAL OF METALS.

TWO SESSIONS ADDED TO IMD FALL MEETING IN CLEVELAND

Two additional technical sessions have been scheduled for the IMD Fall Meeting in Cleveland. The additional session on *Mechanical Properties* will be held at Hotel Carter on Wednesday morning, October 10, and the session on *Alloy Systems and Phase Transformations* will be held on Wednesday afternoon.

One of the principal reasons for adding sessions to the Fall Meeting program is the fact that the IMD program at the Annual Meeting in February will be greatly curtailed because of space limitations. By scheduling additional sessions in October 1956, a delay of a year can be avoided in presenting recently approved papers.

Papers scheduled for these two sessions are listed below:

WEDNESDAY, OCTOBER 10

9:00 to 10:30 am, English Room

Research Summaries—Mechanical Properties

L. L. Seigle and M. Gensamer, Chairmen

Tensile Deformation of Silver as a Function of Temperature, Strain Rate, and Grain Size: R. P. Carreker, Jr., General Electric Co.

Prot Fatigue Study of an Aircraft Steel in the Ultra High Strength Range: P. W. Ramsey and D. P. Kedzie, A. O. Smith Corp.

Plastic Anisotropy of Zinc Monocrystals: J. J. Gilman, General Electric Co. JOURNAL OF METALS, October 1956.

Constant Strain Rate Bend Tests on Hydrogen Embrittled High Strength Steels: W. Beck, Naval Air Material Center; G. Sachs, and E. P. Klier, Syracuse University. JOURNAL OF METALS, October 1956.

Embrittlement of Ti-Al Alloys in the Range From 6 to 10 Pct Al: F. A. Crossley and W. F. Carew, Armour Research Foundation.

2:00 to 5:00 pm, English Room

Research Summaries—Alloy Systems & Phase Transformations

R. L. Smith and S. C. Carapella, Jr., Chairmen

Sigma Phase in Certain Ternary Systems With Vanadium: J. B. Darby, Jr., and P. A. Beck, University of Illinois.

Constitution of Nickel-Rich Quinary Alloys in the System Ni-Fe-Cr-Ti-Al: A. Taylor, Westinghouse Electric Corp.

Some Aspects of Alloying Onto Germanium Surfaces: J. W. Peterson, Pacific Semiconductors, Inc.; J. McGlasson, Jr., and W. C. Hittinger, Bell Telephone Laboratories, Inc.

Electrical Resistance Study of the Effects of Oxygen on the Allotropic Transformation of Titanium: L. A. DePue and E. J. Chapin, Naval Research Laboratory.

Central Region of the Mg-Zn Phase Diagram: J. B. Clark, Dow Chemical Co., and F. N. Rhines, Carnegie Institute of Technology.

Magnetic Method for the Measurement of Precipitate Particle Sizes in a Cu-Co Alloy: J. J. Becker, General Electric Co.

Titanium-Rich Corner of the Ti-Si System: F. A. Crossley, Armour Research Foundation, and D. H. Turner, Titanium Metals Corp. of America.

On the Kinetics of the Pearlite Reaction: J. W. Cahn, General Electric Co.

BOOKS

MEMBERS, ORDER BOOKS LISTED BELOW THROUGH AIME—Address Irene K. Sharp, Book Department. Ten pct discount given whenever possible.

Engineering in History, by R. S. Kirby, S. Withington, A. B. Darling, F. G. Kilgour, *McGraw-Hill Book Co.*, $8.50, 530 pp., 1956.—The combined efforts of engineers and historians have produced this survey of engineering from 6000 B.C. to the present which is ". . . a general introduction to the subject rather than a definitive history."

Resistance Welding, Theory and Use, by Resistance Welding Committee, American Welding Society, *Reinhold Publishing Corp.*, $4.50, 155 pp., 1956.—Full details are presented on resistance welding from a statement of basic principles through processes, inspection, and testing, including such new developments as slope control and the welding of aluminum.

Modern Chemical Processes, Vol. 4, by the Editors of Industrial & Engineering Chemistry, *Reinhold Publishing Corp.*, $5.00, 202 pp., 1956.—This inventory of American chemical technology is a reference book for the practicing industrial chemist, the chemical engineer and the advanced student in these fields. Nineteen recently developed chemical processes now in operation are described as to background, details of plant installation, process and operation of plants, economics of process, personnel, and future prospects, including technological improvement of the process.

Phase Diagrams for Ceramists, by Ernest M. Levin, Howard F. McMurdie, and F. P. Hall, *The American Ceramic Society*, $10.00, 286 pp., 1956.—Over 800 diagrams are classified in the following groups: metal oxide systems, systems containing non-metallic oxides, systems containing halides, sulfides, etc., and water-containing systems. Sources of the diagrams are indicated, and indexes by authors and constituent oxides or materials are provided. An introductory section includes definitions, a selected bibliography, and a general discussion and interpretation of phase diagrams.

The Electrolytic and Chemical Polishing of Metals in Research and Industry, by W. J. McG. Tegart, *Pergamon Press Inc.*, $4.50, 129 pp., 1956.—This concise critical summary of the mechanism of electrolytic polishing and its applications in industry and research gives practical information on apparatus, solutions, methods for polishing specific metals, and precautions to be taken in utilizing the process. Separate sections deal with finishing, machining, surface preparation, and electroplating.

High Temperature Technology, edited by I. E. Campbell, *John Wiley & Sons*, $15.00, 526 pp., 1956.—The contributions of 35 experts are arranged in four sections: the development of refractories and high-temperature techniques; materials; methods; and measurements. The treatment of metallic materials is brief, but sintering methods are considered at length, and both conventional and novel furnace types are described. Specialized mechanical and physical property tests, and high-temperature optical and X-ray techniques are discussed in the section on measurements.

Symposium on Metallic Materials for Service at Temperatures Above 1600°F., ASTM Special Technical Publication No. 174, *American Society for Testing Materials*, $3.50, 193 pp., 1956.—The 14 papers included deal with the properties, testing, and applications of a variety of materials: nimonic alloys; Inconel 700; molybdenum alloys; cermets; carbides; chromium-nickel alloys; zirconium coatings, etc. References are listed after most of the papers.

Resistance of Materials, by F. B. Seely and J. O. Smith, *John Wiley & Sons Inc.*, $6.50, 454 pp., 4th ed., 1956.—Revision of a book originally published in 1925 and intended for use as a text, this work now features newer and more realistic approaches to the problems of complex stresses and combined loads.

The Surface Treatment and Finishing of Aluminium and its Alloys, by S. Wernick and R. Pinner, *Robert Draper Ltd.*, $12.00, 542 pp., 1956.—This work brings together *all* the available processes for use on aluminum, including discussions of theory and references which will be of use to specialists. The attention of engineers is particularly directed to sections dealing with corrosion of aluminum, classification of alloys, and selection of alloy in relation to the finish required.

Oxygen in Iron and Steel Making, by J. A. Charles, W. J. B. Chater, and J. L. Harrison, *Interscience Publishers, Inc.*, $6.50, 291 pp., 1956.—This book aims at a clear assessment of the various oxygen applications to be made, by presenting a critical review of information already published and the results of new trials hitherto unavailable. The subject is discussed in three parts: treatment of the molten metal with oxygen, blast enrichment in solid fuel combustion, and flame enrichment.

Professional Engineers' Examination Questions and Answers, by Wm. S. LaLonde, *McGraw-Hill Book Co.*, $6.50, 350 pp., 1956.—Over 500 questions and answers selected from actual examinations, designed to assist candidates in their preparation for Engineer-in-Training Certificates, or Professional Engineer or Land Surveyor Licenses.

Metallurgical Thermochemistry, by O. Kubaschewski and E. LL. Evans, *John Wiley & Sons*, $10.00, 410 pp., 2nd ed. 1956.—This expanded and corrected monograph intended for research workers and process metallurgists concentrates on chemical thermodynamic theory in reaction problems, experimental techniques for determining thermochemical data, values of thermochemical constants, and practical application of thermochemical methods.

(Continued on page 1490)

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Report On Education

The education committee of AIME's Minnesota section has issued a report on its 1956 program. Continuing a practice begun in 1952 by W. R. Van Slyke, the committee's activities were designed to stimulate and foster the interest of Minnesota high school students in mineral industry careers.

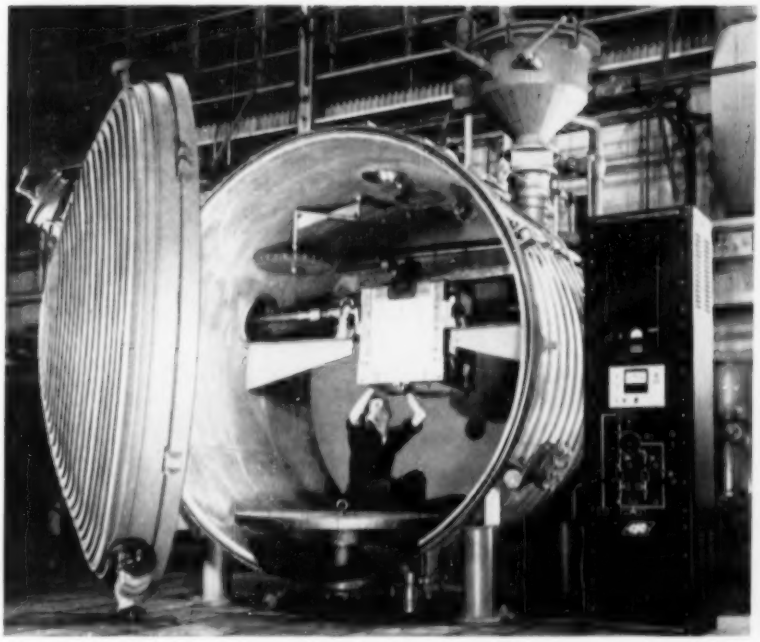
Questionnaires to determine the interest of each school in a visit from an industry representative were dispatched to 158 public and parochial high schools throughout the state. Despite the inclusion of reply forms and stamped, self-addressed envelopes, however, only 78 schools responded.

Meetings restricted to students interested in and capable of higher education were arranged at 44 schools, and packets containing data on curricula, scholarships, etc., were sent to 14 additional institutions where personal visits were impossible. The principal feature of the actual meetings was a talk given by a practicing engineer, supported by booklets and pamphlets, data on engineering schools, and demonstrations of some of the interesting operations of the industry. A total of 1617 students attended, of which 643 were sufficiently interested to request additional information.

Despite the difficulties of making a realistic appraisal of the program's value, the committee felt that the increased percentage of students showing greater than average interest indicates some measure of success for its efforts over the years.

A recognition of the fact that the emphasis on upperclassmen and students who have already demonstrated a bent for engineering imposes a serious limitation on the program's potential effectiveness prompted the committee to recommend several new approaches. Wider use of demonstrations, movies, and supporting literature, as well as direct talks with younger students and community groups, have been suggested as means of contacting more potential mining engineers. The committee also recommended concerted efforts on the part of mining companies to encourage summer employment for interested students, and to stress more forcefully the benefits accruing from a career in the mineral industry.

The report's conclusions suggested the possible value of a full time director for its activities. Should the sponsoring mining companies deem an expanded program necessary and worthwhile, the committee recommends for their consideration a policy which would encourage better and extended courses in science and mathematics in preparatory schools, and rewards to practicing mineral engineers which would be enticing to the younger generation.



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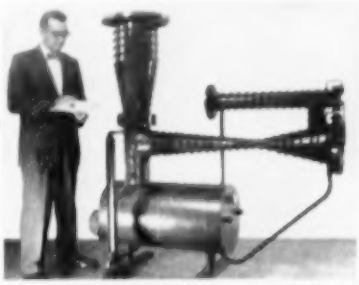

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AROUND THE SECTIONS

• The **Connecticut Section** held its first meeting of the 1956-57 year on September 25, with a paper on *Factors Affecting the Properties of Sintered Structural Parts*, by Carl G. Johnson, featured. Plans for the remainder of the year include a November 27 meeting in Bridgeport with W. A. Backofen of MIT speaking on *Mechanical Metallurgy*; a January 22 session in New Haven on *New Developments of Copper Alloys* by D. K. Crampton of Chase Brass & Copper Co.; and one in Waterbury on March 26 with P. C. Rossin of Universal-Cyclops Steel Corp. discussing *Metallurgical Aspects of Vacuum*.

• When the **St. Louis Section** held their dinner-meeting in the Hotel York on September 14, the featured speaker was Frank C. Mansfield, general superintendent, Madison Div., Dow Chemical Co. Mr. Mansfield who has practiced law and was formerly director of industrial relations for Emerson Electric & Manufacturing Co., reviewed the changes in labor relations and their impact on management and the public.

• The **El Paso Metals Section** met on September 12, in the Mirror Room, Hotel Cortez. Featured speaker at the dinner was R. T. Savage, research engineer, who discussed *Petroleum Refining at the El Paso Refinery of the Standard Oil Co. of Texas.*

A prospector searches for uranium ore with pick and geiger counter in this scene from the film, *The Petrified River.*

The Petrified River, a 28 min, 16 mm sound film on the peaceful uses of uranium, is available from Modern Talking Picture Service. Union Carbide & Carbon Corp., which made this color film, is offering free loan prints for group showings to business and professional societies, service clubs, and other adult organizations. To obtain your print, write to Modern Talking Picture Service Inc., 3 East 54th St., N. Y. 22, specifying first choice of playdate and at least one alternative date.

The Metallurgical Society of AIME

(Continued from page 1433)

The progress report of the Study Committee for Implementation of the Long-Range Plan appeared in JOURNAL OF METALS, *August 1956. The sections given here and on page 1433 are those which pertain to the proposed Societies of AIME.*

a) This section **will be implemented** upon approval of the new Society bylaws and will require revision of the AIME bylaws.

The President's transportation, but not food or lodging expense, should be paid by AIME with an equal local to be determined annually by the Board.

5. **Sections**

As sections over the coming years will be influenced more by professional than by geographical lines, each Society should be given authorization to set up its own geographical areas and organize sections to meet its requirements. Until changed by the Board, the minimum requirement for the setting up of any section should continue to be 25 members.

Local sections can and should be flexible in their organization and operation. Some may be organized on a geographical basis, and some on a professional basis, as was the object of the Long Range Planning Committee to foster a reorganization of local sections, but in each section there should be freedom to organize according to the needs and wishes of its membership. The Council of Section Delegates may be continued as an all-Institute organization, with its functions changed somewhat and some organization of section delegates on a society basis.

a) The responsibility for the organization of new Local Sections and for the promotion of the welfare of the Local Sections is recognized as being an All-Institute function of the utmost importance. Hence, this responsibility goes beyond the scope of the individual Societies. **It is recommended** that the President of AIME appoint a committee of three from the AIME Board of Directors to be called the Committee on *Section Affairs*. This committee should include one member from each of the three Societies. For the sake of continuity each member of this committee should have a tenure of three years. To establish a system of rotation, for the first year a member from one of the Societies should be appointed for a one-year term, a member from the second Society for a two-year term, and a third member from the third society for a three-year term. Thereafter one member would be appointed each year as a replacement. Senior member in service on committee would act as chairman.

7. **Initiation Fees and Dues**

The Committee recommends that for the next three year period initiation fees should be reduced from $20 to $15, and the respective Society be refunded the $5.

a) After a review of the Institute budget the committee concludes that, as desirable as it may seem to be, **implementation** of section 7a is **impossible** at the present time.

The Committee believes that the dues for all three societies should be the same, and that for the time being at least, the $20 fee should be retained.

d) This section **is beyond the scope** of the bylaws of the new Societies but states the policy as it exists today.

8. **Finances**

Each society should have full responsibility for operating at a profit as shown by the AIME books. After expenses have been met, each society should have authority to spend all surplus funds after 25 percent of such surplus funds have been set aside for the interests of the AIME as a whole.

a) This section **will be implemented** upon approval of the new Society bylaws and a revision of AIME bylaws.

9. **Bylaws**

The AIME Bylaws should be rewritten and simplified.

a) The committee **recommends** that immediate steps be taken to rewrite the AIME bylaws in accordance with the philosophy of the Long-Range Plan and with the modifications suggested in this report.

10. **Meetings**

The Committee recommends to the Board that a decided change should be made in the Annual Meeting program. For example, the number of technical sessions should be reduced, one or more joint sessions of the three societies be organized, and luncheon meetings be addressed by outstanding speakers on timely subjects of a general nature.

All business should be divorced from the Annual Banquet and only top awards should be given at that time. The other awards should be given at society or regional dinners or meetings, which it is believed will be strengthened by the transfer to them of some of the technical sessions.

The President should make his report on State of The Institute at an afternoon session during the Annual Meeting.

a) The whole of Section 10 **is being implemented** this year at the meeting in New Orleans. The committee and its correspondents are practically unanimous in agreement with this philosophy.

In conclusion, this committee **recommends** that the committee charged with the revision of the AIME bylaws review also the new Society bylaws for uniformity or consistency in the scope and structure of the three Societies.

BOOKS

(Continued from page 1488)

Recommended Equipment and Procedures for the Palletized Loading and Shipment of Refractory Products, *The Refractories Institute.* $1.50, 47 pp., 1956.

Bibliography of Hardness and Hardness Testing, 1937-1955, *Industrial Diamond Information Bureau,* 55c, 1956.—Articles on hardness and hardness testing are listed, arranged by year of publication since 1937. Also included are a list of standard texts and one of national standards.

Ten Year Index to Corrosion, 1945-1954, compiled by Norman E. Hamner and J. F. Van de Henst, Jr., *National Association of Corrosion Engineers,* $7.50, 32 pp., 1956.—This contains a subject index of 4000 reference listings and an author index of 1056 names, each alphabetically arranged.

A complete English translation of the Soviet journal **Metallurgist** and ten reports on applications of radioactivity in metallurgy by Soviet metallurgists have been published by *Consultants Bureau.* The journal is available on a yearly subscription basis at the rate of $95.00 per year.

The ten reports, including translations of all photographic, tabular, and graphic materials, may be had for $75.00, or individually at the rate of $12.50 each. They are: **Role of Refractory Linings of Steel Pouring Equipment in the Contamination of Steel by Nonmetallic Inclusions; Investigation of Mixing Processes in Open Hearth Furnace Baths by Means of Radioactive Isotopes; Kinetics of the Transfer of Sulfur from Pig Iron to Slag CaO-Al_2O_3 Type; Investigation of Non-Metallic Inclusions by Radiography; An Isotope-Exchange Method of Measuring the Evaporation Rate and the Diffusion Coefficient of Metals; Methods of Studying Diffusion with Radioactive Isotopes; Use of Radioactive Isotopes in Investigating Cutting-Tool Wear; Ionization Methods for Detecting Defects in Thick Sections of Metals by γ-Rays; Measuring Thickness and Density by Means of Radioactive Isotopes; An Experiment in the Use of Isotopes for Branding Rolled Steel.**

Personnel Service

(Continued from page 1426)

Metallurgist, young, for educational and promotional type of work for trade association. Will prepare articles and present papers. Some travel. Salary, $6000 to $8500 a year. Headquarters, New York. W3815.

Research Supervisor, metallurgist, to perform and supervise research in the field of high temperature materials. Experience should be such that the man chosen could direct the efforts of a small research group. Areas of research include: study and development of high temperature alloys, studies of creep and relaxation, behavior determination of properties, and specification of materials for high temperature use. Salary, from $10,000 a year depending on experience. Location, upstate New York. W3802.

Metallurgical Engineer, over 35, B.S., with ten years diversified metallurgical experience and knowledge of foundry, welding, and other metallurgical functions. As technical observer will attend conferences, symposiums, etc., and visit industrial concerns to keep abreast of latest European technical developments. Salary, to $10,000 and overseas differential traveling expenses for family and possessions. Initial assignment, two years. Location, Holland. Employer will pay placement fee. C5453.

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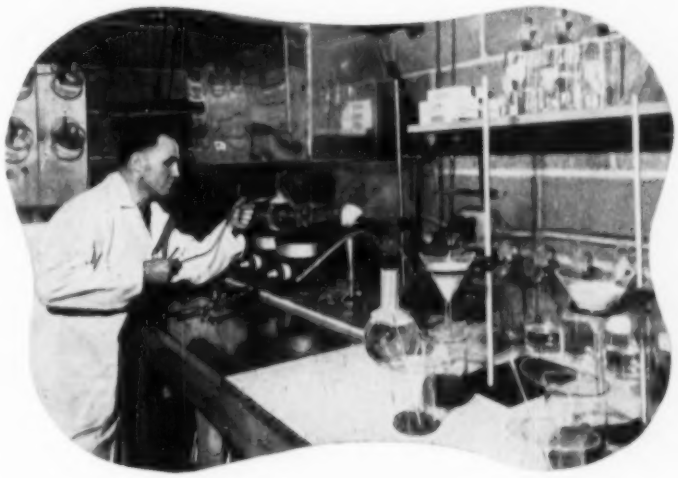

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PERSONALS

The U. S. Chamber of Commerce has announced the following appointments to its 1956-57 Natural Resources Committee: **Frank E. McCaslin,** president, Portland Cement Co., is chairman, **David L. Francis,** president, Princess Elkhorn Coal Co., **George A. Lamb,** business surveys manager, Pittsburgh Consolidation Coal Co., and **Harry LaViers,** president, South-East Coal Co.,—represent the coal industry; **William S. Cumings,** Mining Div., Bethlehem Steel Co., **Endicott R. Lovell,** president, Calumet & Hecla Inc., **Franklin G. Pardee,** president, Lake Superior Iron Ore Assn., **L. J. Randall,** president, Hecla Mining Co., and **O. A. Rockwell,** vice president, The Eagle-Picher Co.—represent the minerals and metals industries; **Fred W. Bartlett,** production director, Socony Mobil Oil Co.—represents the oil and gas producers; and **Harold H. Christy,** The Colorado Fuel & Iron Corp.—represents water supply, flood control, and reclamation.

Rolf Weil has been named assistant professor, department of metallurgy, Stevens Institute of Technology, Hoboken, N. J.

John B. Seastone is director of the technical division, Olin Mathieson Chemical Corp. with offices in New Haven, Conn. He had been research and development manager of the company's metals division.

Ora Clark has been named general superintendent of all operations at the Middletown Works, Armco Steel Corp., Middletown, Ohio.

O. CLARK

Herbert B. Michaelson has been appointed associate editor of the new *IBM Journal of Research and Development.* He joins IBM after ten years of service in the technical information division of Sylvania Electronic's Atomic Energy Div., Bayside, N. J.

C. H. LORIG

Carl D. Post, ASM nominating committee chairman, has announced the 1956-1957 slate. Nominated for president is **Donald S. Clark,** professor of mechanical engineering, California Institute of Technology, while **George M. Young,** The Aluminum Co. of Canada, has been named for the vice-presidency. **C. H. Lorig,** assistant director, Battelle Memorial

C. E. SWARTZ

Institute, will serve another term as treasurer. New appointments to the board of trustees include **A. O. Schaefer,** retiring president, **George A. Fisher, Jr.,** International Nickel Co., and **Carl E. Swartz,** consulting metallurgist.

A. N. Holden will manage metallurgy for General Electric Co.'s new Vallecitos Atomic Laboratory at Pleasanton, Calif. A member of ASM and the American Nuclear Society, Mr. Holden is 1953 recipient of the AIME Rossiter Raymond Award.

W. A. Mudge has been appointed special representative on educational programs, International Nickel Co. of Canada Ltd. and its U. S. subsidiary, International Nickel Co. Inc. Dr. Mudge had been director, Technical Service Section, Development and Research Div. since 1947. He joined INCO's research department in 1920.

Walter Bonsack recently joined the staff of William F. Jobbins Inc., Aurora, Ill., as a special metallurgical consultant and sales engineer in the West Coast area. While working for the National Smelting Co. in Cleveland, he developed a series of new alloys for pistons. His research study, *The Effect of Minor Alloying Elements on the Properties of Aluminum Casting Alloys,* won him the coveted Dudley Gold Medal, presented yearly for the most outstanding contribution to engineering. Mr. Bonsack has held office in AIME, ASTM, and ASM.

Dwight L. Harris, formerly in the Mining and Metallurgy Dept. at the University of Wisconsin, is now research metallurgist, American Chrome Co., Nye, Mont.

Eugene M. Benson and **Joseph F. Hammond** have joined the staff of Union Carbide Nuclear Co.'s Oak Ridge atomic energy operations as metallurgists.

Clemens C. Sutinen has left the Welded Carbide Tool Co. Inc. to become technical sales engineer with the Powder Metallurgy Equipment Div., Mannesmann-Meer Engineering & Construction Co., Easton, Pa.

Jack C. Bokros is research engineer, Atomic International Div. of North American Aviation, Canoga Park, Calif.

Robert W. Sandelin, holder of five degrees from the University of Minnesota, has recently graduated from the Birmingham School of Law. Although his major occupation is that of chief metallurgist, Connors Steel Div., H. K. Porter Co. Inc., Dr. Sandelin also finds time to instruct evening classes in metallurgy at the University of Alabama's Extension

R. W. SANDELIN

Div. His recent achievement enables him to place the Alabama Bar and the Birmingham Bar Associations among the organizations to which he belongs—a list including AIME, ASM, ASTM, and the Iron and Steel Institute in London.

W. WILSON

William Wilson has taken on the directorship of research and development at A. Finkl & Sons, Chicago. He was formerly supervisor of metallurgy at Ekco Products Co.

Frank W. Glaser, recently appointed director of Mercast Ltd., will represent U. S. interests on the board of directors of this British company.

R. D. Weber has resigned his position with Enfield Rolling Mills, Middlesex, England, to become production engineer, A. B. Svenska Metallverken, Vasteras, Sweden.

Louis J. Rohl has been named vice president and chief metallurgical engineer, United States Steel Corp.

Ralph A. Clark, manager of foundry service, Electro Metallurgical Co., is now located in the company's Cleveland office.

Henry Hahn is in the development metallurgy division of Wright Aeronautical Div., Curtiss-Wright Corp., Wood-Ridge, N. J.

K. C. Vincent is director of the research department, Westvaco Mineral Products Div., Food Machinery and Chemical Corp., Newark, Calif.

Thomas L. Hurst has joined the Research Dept., Monsanto Chemical Co., Everett, Mass. He had been research group leader at the company's Phosphate Div., in Columbia, Tenn.

Frank B. Fargo has left Laclede Christy Co., to become district sales manager, No. Amer. Refractories Co. in Calif. and Denver Fire Clay, Denver.

J. M. Williams is director of research and development, Turbine Parts Div., Utica Drop Forge & Tool Corp., Utica, N. Y. He had been with Metals & Controls Corp., Attleboro, Mass.

Alfonso Merlini is at the University of California's minerals research laboratory in Berkeley, having left the Conservatoire National des Arts et Metiers, in Paris.

Alfred S. Keh is at the Fundamental Research Lab., U. S. Steel Corp., Monroeville, Pa.

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Jose Capmany, industrial and consulting engineer, is now located at Altos Hornos de Cataluña, Bailen 1, Barcelona, Spain.

Henry A. Tuttle and **G. E. Noakes** presented a technical paper on the use of radioactivity for the control and testing of automotive materials at the SAE summer meeting. The session emphasized Ford Motor Co.'s use of nuclear energy as an illustration of the atom's industrial value.

Christopher J. B. Fincham has resigned as lecturer in the metallurgical engineering department, University of Toronto, to work as physical chemist, National Research Corp., Cambridge, Mass.

Harold K. Work and **Harold Margolin** have been given new posts on the New York University faculty. Dr. Work is now professor of research management in addition to his duties as research division director, College of Engineering. Dr. Margolin is associate professor of metallurgical engineering.

C. R. Allison, Jr., has joined Linde Air Products, Cleveland.

Donald H. McIntosh, superintendent, Western Research Section, American Smelting & Refining Co., has been transferred from Salt Lake City to the company's offices in El Paso, Texas.

C. R. McCULLOUGH

C. Rogers McCullough has been appointed deputy director for hazards evaluation in the AEC's Division of Civilian Application. Dr. McCullough will direct the work of developing criteria and standards for the safe design and operation of atomic reactors and other nuclear facilities.

R. W. Diamond has accepted the presidency of the Sixth Commonwealth Mining and Metallurgical Congress, to meet in Canada next year. His duties will be to direct a nation-wide organization appointed to plan and prepare for the conference. Among the plans already laid is a cross-country inspection tour of Canadian mining operations. Congress meetings will be held in eight cities, starting in Vancouver, B. C., on September 8, 1957.

Harold W. Paxton, assistant professor of metallurgical engineering at Carnegie Institute of Technology, Pittsburgh, is currently engaged in research on columbium. Sponsored by General Electric Co., the research program promises to prove valuable in the high temperature field. This metal may be the secret to even faster supersonic speeds.

F. TOWELL, JR.

Frederick Towell, Jr., is with Andes Copper Mining Co., Potrerillos, Chile. He was formerly with Chile Exploration Co., in Chuquicamata, Chile.

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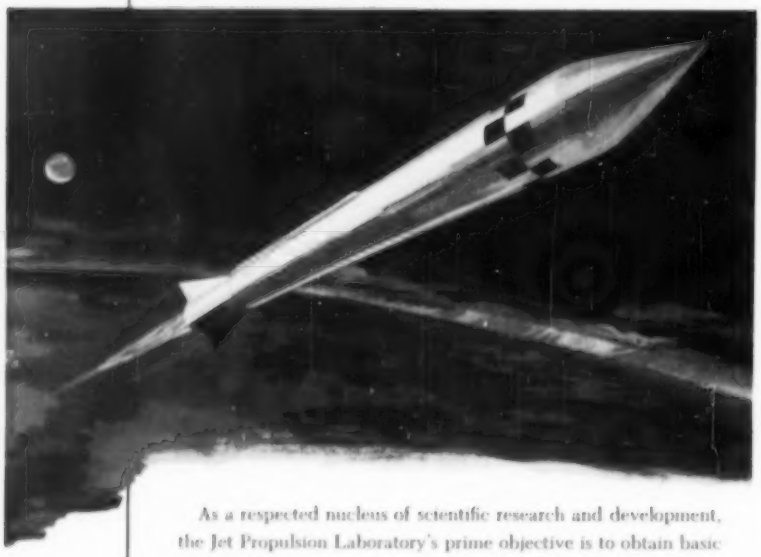

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Metals Branch, AIME

Total AIME membership on Sept. 30, 1956 was 25,668; in addition 2,848 Student Associates were enrolled.

ADMISSIONS COMMITTEE

R. B. Caples, Chairman; F. A. Ayer, Vice-Chairman; A. C. Brinker, R. H. Dickson, C. R. Dodson, R. B. Fulton, T. D. Jones, F. W. Hanson, Sidney Rolle, F. T. Sisco, O. B. J. Fraser, F. W. McQuiston, Jr., A. R. Lytle, L. P. Warriner.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

Members

John Borg, Torrance, Calif.
Willis F. Bradford, Chihuahua, Mexico
Justice N. Carman, Los Angeles
Robert W. Day, Houston
R. B. Fisher, Columbus, Ohio
Henry Wm. Guendel, Hoboken, N. J.
Robert H. Henke, Pittsburgh

Associates

Joseph Campbell, Lackawanna, N. Y.
E. Casas Alatriste, Mexico
Frank C. Cook, Bountiful, Utah
James L. Perkinson, Jr., Warrenville Heights, Ohio

Juniors

Newton H. Johnson, Jr., Tonawanda, N. Y.
Henry Kaplan, Troy, N. Y.
C. A. Krier, Columbus, Ohio
Martin Matekovic, Provo, Utah
J. R. Mihalisin, N. Caldwell, N. J.
B. R. Nijhawan, Jamshedpur, India
E. R. Rowley, New York City
Richard P. Simmons, Natrona, Pa.
Ray Smithson, Jr., Columbus, Ohio
Dan A. Sutch, New York City
I. Umana De Brigard, Bogota, Colombia
John L. Watters, Brackenridge, Pa.

CHANGE OF STATUS

Junior to Member

Michael V. Nevitt, Lemont, Ill.

REINSTATEMENT—CHANGE OF STATUS

Junior to Member

John H. Smith, Welland, Ont.
W. R. Stern, Grants, N. M.
Alfred C. Wooll, Detroit

Student to Member

William G. Fricke, Jr., New Kensington, Pa.
Frank G. Janney, Los Angeles

NECROLOGY

Date Elected	Name	Date of Death
1935	W. H. Burke	July 31, 1956
1909	Edwin J. Collins	Aug. 15, 1956
1919	O. J. Egleston	Aug. 23, 1956
1947	Ralph H. Espach	Aug. 6, 1956
1917	M. B. Gentry	July 31, 1956
1920	Neil M. Gibson	July 10, 1956
1952	A. E. Harris	October 1955
1938	Morton T. Higgs	June 1956
1904	Edwin W. Mills	Unknown
	Legion of Honor	
1955	Charles G. Penland	Unknown
1921	Paul H. Reisher	Dec. 22, 1955
1936	Arthur L. Walker, Jr.	Aug. 7, 1956
1936	A. W. Walker	July 19, 1956

Correction

The item in JOURNAL OF METALS July, page 874 concerning **A. T. Cape** was incorrect. Mr. Cape has been associated with Coast Metals Inc. for 21 years, and is in association with Raymond Equipment Corp.

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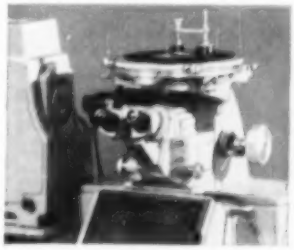

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COMING EVENTS

Oct. 12, AIME, NOHC Eastern Local Section, annual fall meeting.

Oct. 16-18, AIEE, AIME, IRE, and Amer. Physical Soc., conference on magnetism and magnetic materials, Hotel Statler, Boston.

Oct. 22-24, ASA, annual meeting, Hotel Roosevelt, New York.

Oct. 25, 26, AIME-ASME, Joint Solid Fuels Conference, Sheraton-Park Hotel, Washington, D. C.

Oct. 25, 26, ECPD, annual meeting, Engineering Society of Detroit Building, Detroit.

Oct. 28-Nov. 1, Electrochemical Soc., Statler Hotel, Cleveland.

Nov. 2, AIME, Pittsburgh Local Section, NOHC Pittsburgh Local Section, annual off-the-record meeting, William Penn Hotel, Pittsburgh.

Nov. 5, AIME, Boston Local Section. Speaker: R. D. Parks, MIT; subject: *Mining, Minerals, and Metallurgy in India.* Boston.

Nov. 5-7, CIM, annual Western meeting, Vancouver Hotel, Vancouver.

Nov. 7-9, Steel Founders' Soc. of America, annual technical and operating conference, Carter Hotel, Cleveland.

Nov. 8-10, AIME, Mining Branch, Northeast Regional Meeting, Hotel Hershey, Hershey, Pa.

Nov. 13, AIME, NOHC Buffalo Local Section, annual meeting.

Nov. 13-15, Investment Casting Inst., annual meeting, Sheraton Cadillac Hotel, Detroit.

Nov. 14, AIME, NOHC Western Local Section, Rodger Young Auditorium, Los Angeles.

Nov. 27, AIME, Connecticut Local Section. Speaker: W. A. Backofen, MIT; subject: *Mechanical Metallurgy.* Bridgeport, Conn.

Dec. 5-7, AIME, Electric Furnace Steel Conference, Hotel Morrison, Chicago.

Dec. 9-12, AIChE, annual meeting, Statler Hotel, Boston.

Jan. 17-18, 1957, EJC, annual meeting, Statler Hotel, New York.

Feb. 24-28, AIME Annual Meeting, Roosevelt and Jung Hotels, New Orleans.

Mar. 10-16, EJC Second Nuclear Engineering and Science Congress, Convention Hall, Philadelphia.

Mar. 13, NOHC Chicago Local Section, annual all-day meeting, Del Prado Hotel, Chicago.

Mar. 25-29, ASM And Others, Tenth Western Metal Exposition and Congress, Pan-Pacific Auditorium and Ambassador Hotel, Los Angeles.

April 5, 6, AIME, Pacific Southwest Mineral Industry Conference. Sponsor: Nevada Local Section; cosponsors: San Francisco and Southern California Local Sections. Reno.

Apr. 8-10, AIME National Open Hearth Steel and Blast Furnace, Coke Oven, and Raw Materials Conferences, William Penn Hotel, Pittsburgh.

Apr. 11-13, AIME, Pacific Northwest Regional Conference, Multnomah Hotel, Portland, Ore.

Apr. 16-17, AIME Regional Conference on High Temperature Alloys, Hotel Manger, Cleveland.

May 5-9, American Ceramic Soc., annual meeting, Statler Hotel, Dallas.

May 28-29, AIME Reactive Metals Conference, Ambassador Hotel, Los Angeles.

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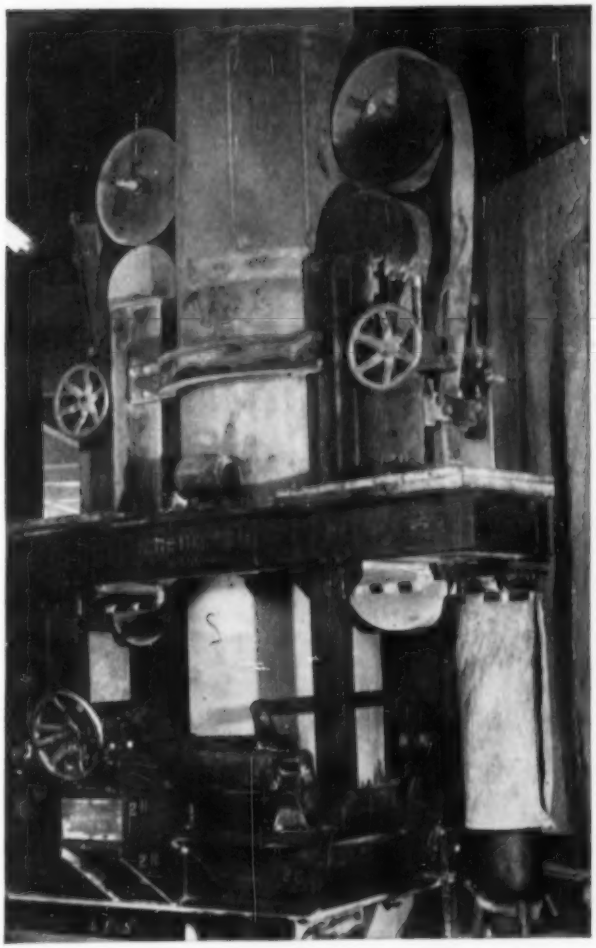
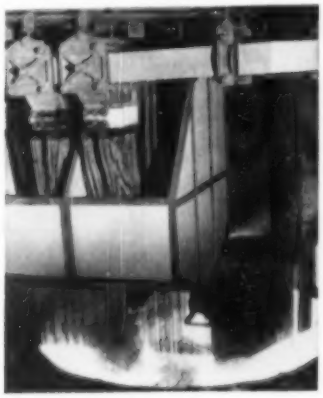
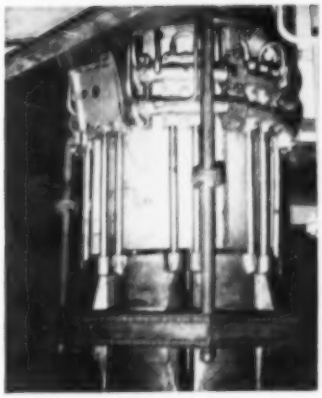


DEPENDABILITY designed and built into Lectromelt furnace equipment accounts for its widespread use around the world. Because furnaces are often installed at mine mouths and other out-of-the-way places, they must operate with a minimum of down-time for repairs.

VERSATILITY demonstrated by Lectromelt furnaces throughout the past forty years makes them readily adaptable to variations in processes. Experience gained by Lectromelt engineers on electrothermic problems enables them to advise you on the use of electric-arc furnaces in high temperature chemistry.

For this help and for a copy of Catalog No. 105, write Electrothermic Division, Lectromelt Furnace Company, 326 32nd Street, Pittsburgh 30, Pa. (a McGraw Electric Company Division).





Two 7500 KVA Lectromelt Furnaces with 35-inch self-baking electrodes are employed by Ferro-Metals on ferroalloys and ferro-silicons.

Manufactured in . . . ENGLAND: Birlec, Ltd., Birmingham . . . FRANCE: Stein et Roubaix, Paris . . . BELGIUM: S. A. Belge Stein et Roubaix, Bressoux-Liege . . . SPAIN: General Electrica Espanola, Bilbao . . . ITALY: Forni Stein, Genoa . . . JAPAN: Daido Steel Co. Ltd. Nagova

*REG. T. M. U. S. PAT. OFF.

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DATA ON VOLMEX 81 . . .

HOW VOLMEX® 81

performs as a high volatile ingot mold coating when applied . . .

(1) Wet (2) Dry (3) At varying ingot mold temperatures

Volmex 81 is a highly volatile ingot mold coating which has been tested and adopted by a number of steel plants. The charts below are based on actual data obtained during such trial runs. Because of the differing practices employed by various companies, we have included several variables. First, because Volmex 81 can be applied either dry or with water as the carrier (spraying, swabbing or dipping are all practical), we have presented test figures on its use, both wet and dry. Second, we have included data on a range of ingot mold temperatures from 100°F. to 700°F., and third, we offer for comparison the results of a one-hour and a three-hour time-at-mold temperatures. No matter what method of application was used, Volmex 81 was found to repel metal splashes effectively before they could solidify and cling to the mold wall. At the same time, enough of the graphite-base coating was left at the metal/mold interface to keep the main body of the pour from clinging when it reached the point of splash, thus reducing surface defects. For wet application, Volmex 81 is easily stirred into suspension and remains in that state for hours without re-agitation. Volmex 81 is the most volatile of the United States Graphite Company ingot mold washes. Others, in order of their volatility are: 90-B (non-volatile), MEX (very little volatility), and VOLMEX (volatile, but less so than VOLMEX 81). Write us for more extensive details or our engineering staff is available for on-the-spot assistance. Mold spray and mixing equipment are ready for your use in tests you may want to arrange.

Table I **Volatility of VOLMEX 81 Ingot Mold Wash**

Mold Coating Volatility Test—VOLMEX 81 Water Application 2.75 lbs. powder/gal. water—Period—1 Hour at	Temperature 300°F.	500°F.	700°F.
% loss after heating for 1 hour	74.3	73.9	75.4
% loss on ignition at 1900°F. after 1 hour at specified temperature	16.1	14.4	11.3
Total percent volatile matter	90.4	88.3	86.7

Table II

Mold Coating Volatility Test—VOLMEX 81 Dry Application—Period—1 Hour at	Temperature 100°F.	300°F.	500°F.	700°F.
% loss after heating for 1 hour	0.1	0.8	0.9	2.8
% loss on ignition at 1900° F. after 1 hour at specified temperature	60.8	60.4	59.7	56.5
Total percent volatile matter	60.9	61.2	60.6	59.3

Table III

Mold Coating Volatility Test—VOLMEX 81 Dry Application—Period—3 Hours at	Temperature 100°F.	300°F.	500°F.	700°F.
% loss after heating for 3 hours	0.1	0.8	1.1	4.5
% loss on ignition at 1900°F. after 3 hours at specified temperature	60.6	59.6	59.7	53.1
Total percent volatile matter	60.7	60.4	60.8	57.6

You will note in the first chart which is the wet application, that the loss is all of the water contained plus a slight amount of the remaining volatile. Since on a weight basis, the powder is about ¼ of the make-up, if you will multiply the percent loss figures at 1900°F. by four, you will get an idea of the amount of volatile which would be present for loss during the pouring operation.

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